FEASIBILITY OF DESIGNING A SPOUTED BED GASIFIER

The SNC Group

JULY 1982

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July 16, 1982

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RE: Determination of the Feasibility of Designing a Process Development Unit for the Commercialization of a Spouted Bed Gasifier

Dear Mr. Skubnik:

We are pleased to submit the final report in five (5) copies for your approval/comments. On receipt of your comments, we will revise the report accordingly.

We are also enclosing five (5) copies of the work statement for the Phase II of this project. This work statement pertains to detailed engineering of the Process Development Unit of the spouted bed gasifier.

Yours truly,

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Project Manager

Encls.

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DETERMINATION OF THE FEASIBILITY

OF

DESIGNING A PROCESS DEVELOPMENT UNIT

FOR THE COMMERCIALIZATION OF A SPOUTED BED GASIFIER

FINAL REPORT

BY

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ABSTRACT

A 12 tonnes dry coal per day Spouted Bed Gasifier Process Development unit was scaled-up on the basis of experimental work carried out at the University of British Columbia, Vancouver, B.C. The scale-up process involved model analysis using dimensionless groups and mathematical modelling. The set of differential equations modelling the spouted bed gasifier was solved using fourth-order Runge-Kutta-Gill numerical integration method. The solution was transformed into a computer program simulating the spouted bed coal gasifier. A 1.0 meter internal diameter and 9.8 meter high P.D.U. was designed by using model analysis. A conceptual design of a process development facility for gasifying 12 tonnes dry coal per day was obtained and a cost estimate was prepared. Several prospectives sites were examined for locating the designed facility.

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1.0 INTRODUCTION

1.0 INTRODUCTION

1.1 Objective and Scope

This study was requested by CANMET through the Department of Supply and Services, Canada, under contract number OSQ81-00183, titled "Determination of the Feasibility of Designing a Process Development Unit for the Commercialization of a Spouted Bed Gasifier."

The work statement required SNC to determine if it was feasible to design a 12 tonnes per day Process Development Unit (P.D.U.) spouted bed coal gasifier based on the experimental work carried out at the University of British Columbia, Vancouver, British Columbia. If feasible, SNC had to prepare a preliminary design of such a facility, provide an order of magnitude estimate of the capital and operating costs and select a possible site for creation of such a facility.

1.2 Spouted Bed Reactor

The spouted bed reactor technology is still in its infancy despite a successful application in grain-drying for the past thirty years (13). One of the major reasons has been the advent of the fluidized bed reactor which has found extensive application as a gas-solid catalytic reactor capable of functioning at high temperatures and high pressures. As shown in Figure 1, the spouted bed reactor is a cylindrical vessel with a conical bottom. The spouting fluid which enters from a single orifice at the apex of the cone travels up a central spout region as a jet of high voidage, while percolating into the downward-moving annular bed of solids. Particles entrained in the spout travel upward to form a fountain from which they rain over the top of the bed.

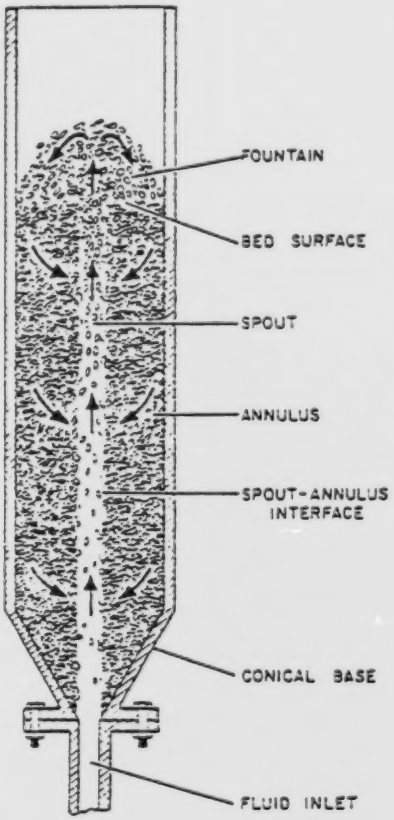

FIGURE 1. A SCHEMATIC DIAGRAM OF A SPOUTED BED REACTOR.

In the annulus the solids move downward at about packed bed voidage. The spouted bed is back-mixed with respect to solids flow although the annulus section is a slow moving packed bed. Thus, the annulus can be viewed as a counter-current moving-bed while the spout can be regarded as an entrained-bed (7). The hydrodynamics of spouted bed is more complex than that of stand-alone fixed bed, fluidized bed, moving bed, or entrained bed reactors. This is another reason for the slow development of spouted bed reactor technology.

1.3 Coal Gasification in Spouted Bed Reactor

Increased interest in gasification of coal for energy and chemical production and the success of fluidized bed gasifiers, has raised the possibility of using spouted bed reactors for gasification. A coal gasifier is characterized by coal consumption and gas yield, the practical range of operating parameters, the reactor geometry, feed rates and the type of coals that can be used. Both the fluidized bed and the entrained bed reactors suffer from high carry-over of char and ash due to a small particle size. These reactors operate at a uniform bed temperature and produce a low-tar gas (7). The fluidized bed gasifier requires special processing technology if the coal has a Free Swelling Index (F.S.I.) of about 1.5. The moving bed gasifier produces a high-tar high-BTU gas, and the dust entrainment is low but it is difficult to control at large coal throughputs.

The spouted bed gasifier may exhibit a combination of these characteristics. The annulus is an agitated moving bed continuously renewed by solid cross-flow between the spout and the annular zones. The continuous internal recycle of solid particles provides sufficient gas-solid contact to yield a uniform bed

temperature at any level. A spouted bed gasifier can process larger coal particles than a fluidized bed or an entrained bed thereby reducing the cost of unit operations. It is also possible to use agglutinating coals because bed expansion, constant attrition between particles, and the larger inlet reduce the probability of clogging due to agglomeration. The disadvantages of a spouted bed gasifier are the limit on bed depth and the entrainment of char. There also exits a minimum spouting velocity which controls air/coal ratio for a given bed geometry. The spouted bed gasifier is thus characterized by the gas and particle velocities in each zone, the concentration of various chemical species in each zone, the bed voidage, the spout diameter, the spout voidage, the minimum spouting velocity, and the maximum spoutable bed depth.

Development of this gasifier has been pioneered by Wakinson et al. (20) at the University of British Columbia. Three types of western coals have been gasified in the experimental unit: a subbituminous non-coking coal supplied from Forestburg Colliery, in Central Alberta, a moderately coking (F.S.I=3.5) bituminous coal from the Crowsnest coal field, in Southeast British Columbia, supplied by Coleman Colliery, and a highly coking (F.S.I.=7) bituminous coal from the Peace River coal field, in Northeast British Columbia, supplied by B.P., Canada.

1.4 Methodology of Scale-Up

A commercial chemical reactor is not a stand-alone system capable of functioning independent of other plant equipment, although, it is the heart of the entire system. Hence, the design of the reactor is crucial to efficient operation of the plant. The mandate of any chemical engineer designing a chemical reactor is to optimize the production of desirable chemicals by transforming

the reactants using a thermodynamically viable chemical network under practical operating conditions in an economically sized equipment. In order to meet this mandate the engineer has to develop tools which facilitate prediction of reactor behavior and product composition at specified operating conditions. The conventional methodology of reactor scale-up requires several semi-works and pilot plant stages before sufficient information is gathered. This approach is cautious and secure. But, the capital costs are high and development time is unreasonably long.

An alternative approach is outlined in Figure 2. This rational alternative relies upon the availability of necessary and sufficient experimental data of reasonable accuracy to shorten the design procedure. The computer-aided mathematical simulation step in such a reactor-design process will yield consistent results if all of its components are reliable. But, if the relevant physico-chemical information is unavailable or inaccurate, or if the synthesis is hampered by the complexity of the real system the predicted performance will not match observed results. Keeping this limitation in our sight the model analysis approach using dimensionless groups has been incorporated in the main stream of the reactor scale-up procedure. It allows the scale-up process to proceed along the traditional lines with additional support from the mathematical model.

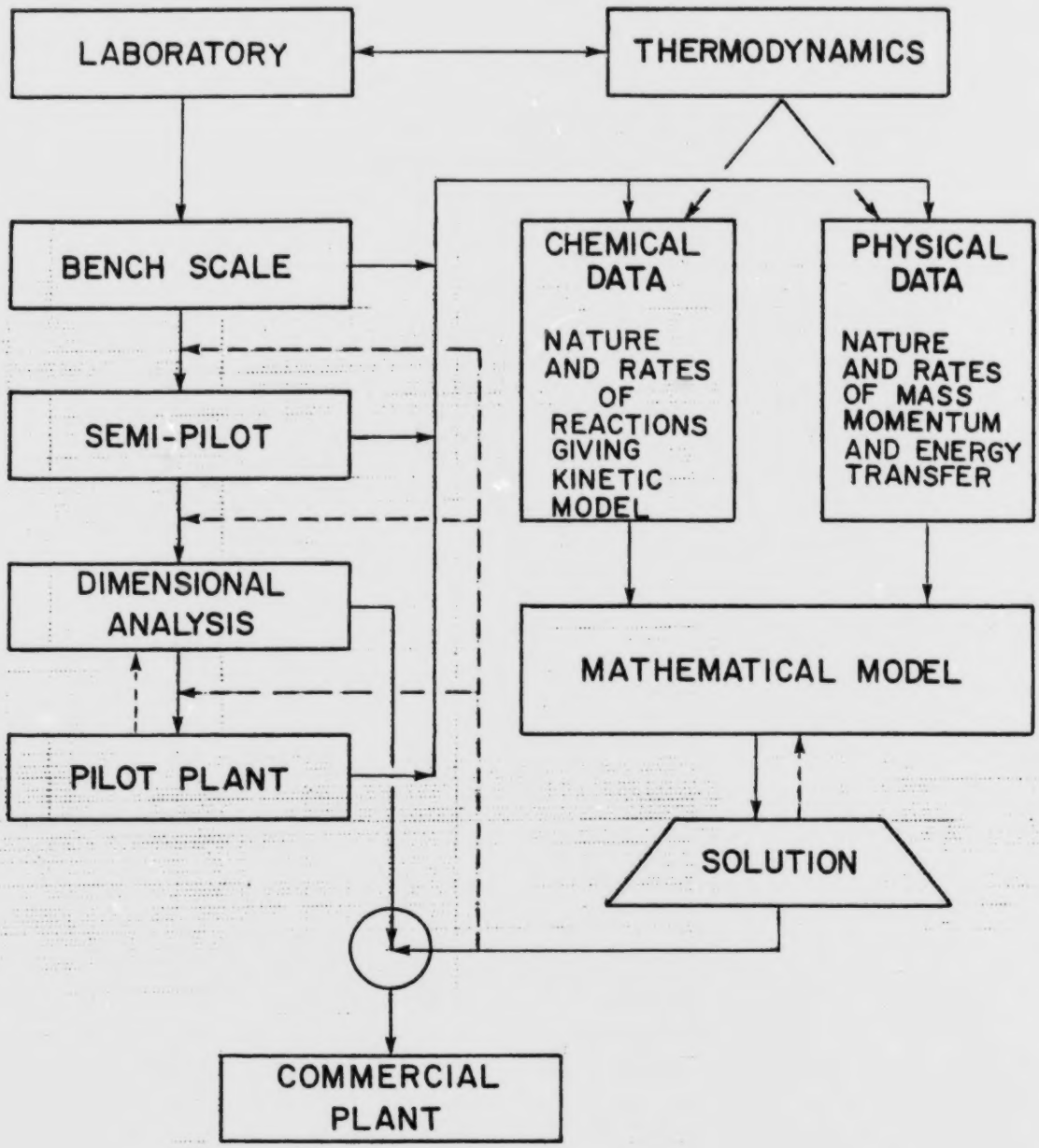

FIGURE 2 - A SYSTEMS APPROACH TO REACTOR DESIGN

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2.0 SCALE-UP BY MODEL ANALYSIS

2.0 SCALE-UP BY MODEL ANALYSIS

2.1 Basis For Scale-Up

The model analysis approach is based upon quantitative methods of correlating the behavior of a model to the large-scale commercial unit. This approach therefore uses dimensionless groups that maintain dynamic, kinematic, and kinetic similarity between the model and the scaled-up unit.

In modelling a chemical reactor the kinetic similarity is as important as the hydrodynamic similarity. Thus, good kinetic data improves predictability. In the present case, relevent data on devolatilization and combustion of coal in spouted bed gasifiers are not available. This problem is overcome by making an assumption that kinetics of coal devolatilization and gasification in spouted bed reactors can be approximated by the kinetics in a fluidized bed gasifier.

The scale-up equations are derived using the same processing condition for both the model and the prototype. Hence, the physical and chemical properties of the various process streams remain constant and do not affect the scale-up. Similarily, if there exist geometrical relationships between the model and the prototype, the shape factors and other constants cancel out. As a result, the scale-up equations may be reduced to simple correlations consisting of linear dimensions and operating variables.

2.2 Scale-Up Equations

2.2.1 Pattipati and Wen Equation (14)

The kinetic similarity between the model and the prototype is obtained from Pattipati and Wen's study of devolatilization and

combustion of coal in fluidized bed reactors (14). Their work suggests that the rate combustion of a coal particle is proportional to the particle diameter, that is,

$$\dot{M}_c = Kd_p^n \qquad \ldots(2\text{-}1)$$

where, n, is equal to 2 for chemical reaction control regime and, 1.57 for diffusion control regime. They further suggest that an exponent value of n = 1.8, be used for gasification of particles with d_p > 2 mm, at a reaction temperature between 750 and 950°c.

K is a constant of proportionality dependent upon the mass transfer coefficient between the emulsion phase and the particle, the reaction rate constant, and the oxygen concentration in the emulsion phase. If the same d_p, C, T, P, fluid composition, and coal density are used in both the model and the prototype, the combustion and diffusion rates will remain constant.

2.2.2 Mathur-Gishler Equation (13)

As a spouted bed gasifier is characterized by the minimum spouting velocity, a kinematic fluid flow similarity was initially expressed by the dimensionless Mathur-Gishler equation (13):

$$U_{ms} = \left(\frac{d_p}{D_c}\right)\left(\frac{D_i}{D_c}\right)^{1/3}\left[2gH\left(\frac{\rho_p}{\rho_g} - 1\right)\right]^{1/2} \qquad \ldots(2\text{-}2)$$

which may be rearranged as

$$\frac{U_{ms}^2}{2g} = H\left(\frac{d_p}{D_c}\right)^2\left(\frac{D_i}{D_c}\right)^{2/3}\frac{\rho_p}{\rho_g} - 1 \qquad \ldots(2\text{-}3)$$

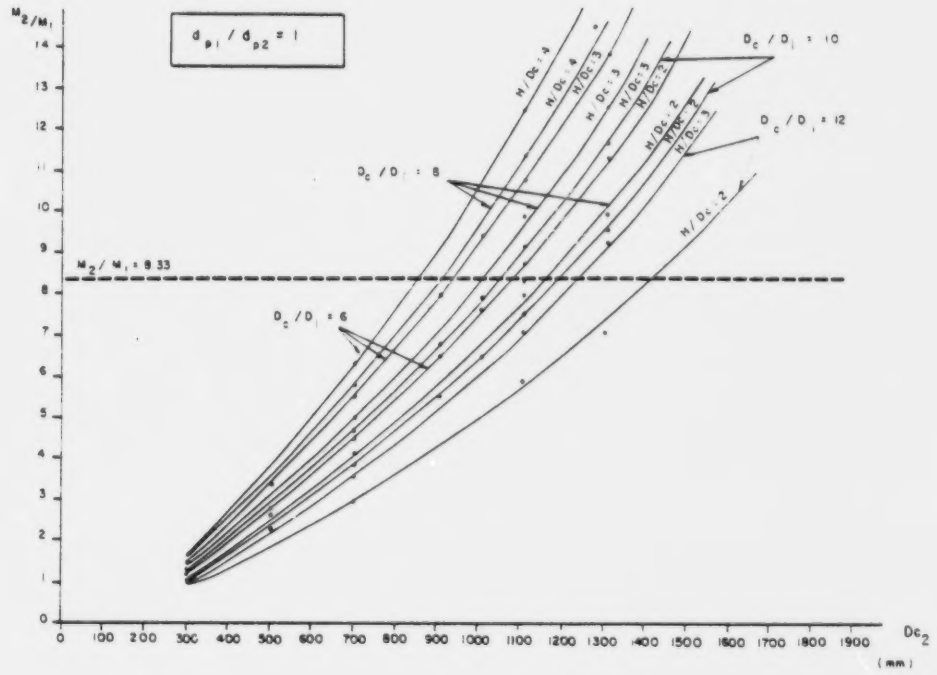

FIGURE 3. RESULT OF SCALING-UP BY MATHUR-GISHLER EQUATION (2-2).

Therefore, for geometrically similar systems, 1 and 2 (model and prototype), the ratio of minimum spouting velocities is given by,

$$\left(\frac{U_1}{U_2}\right)^2 = \left(\frac{H_1}{H_2}\right)\left(\frac{D_{c2}}{D_{c1}}\right)^{8/3}\left(\frac{D_{i1}}{D_{i2}}\right)^{2/3}\left(\frac{d_{p1}}{d_{p2}}\right)^2 \quad \ldots(2\text{-}4)$$

Material input to the gasifier is given by

$$M = K\ C\ U_i\ D_i^2 \quad \ldots(2\text{-}5)$$

where, $U_i = (D_c/D_i)^2\ U_{ms}$ $\ldots(2\text{-}6)$

Hence, the ratio of material input is,

$$\frac{M_1}{M_2} = \left(\frac{D_{c1}}{D_{c2}}\right)^2\left(\frac{U_1}{U_2}\right) \quad \ldots(2\text{-}7)$$

Substituting equation (2-4) in equation (2-7) yields,

$$\frac{M_1}{M_2} = \left[\frac{D_{c1}}{D_{c2}}\right]^{2/3}\left[\frac{D_{i1}}{D_{12}}\right]^{1/3}\left[\frac{H_1}{H_2}\right]^{1/2}\left(\frac{d_{p1}}{d_{p2}}\right) \quad \ldots(2\text{-}8)$$

where, M_2/M_1, the a scaling-up ratio. This equation is plotted in Figure 3 for the ratio, d_{p1}/d_{p2}, equal to 1. In the present case the model dimensions are obtained from Watkinson et al. (20) and the prototype is a 12t/d (dry basis) spouted bed coal gasifier P.D.U., thus, the scale-up ratio M_2/M_1 is 8.33.

2.2.3 Uemaki-Kugo Equation (13)

The kinematic fluid flow similarity may also be obtained by using the Uemaki-Kugo equation (13):

$$\frac{k_m d}{D_v} = 0.00022 \left(\frac{D_c}{H}\right) \left(\frac{d_p U_s \rho g}{\mu_g}\right)^{1.45} \quad \ldots(2\text{-}9)$$

Now,

$$U_i = (D_c/D_i)^2 \, U_s \quad \ldots(2\text{-}10)$$

Substitution of equation (2-10) in equation (2-5) and solving for, U_s, gives:

$$U_s = M/KCD_c^2 \quad \ldots(2\text{-}11)$$

Hence, for systems 1 and 2 the velocity ratio is,

$$\frac{U_1}{U_2} = \left(\frac{M_1}{M_2}\right) \left(\frac{D_{c2}}{D_{c1}}\right)^2 \quad \ldots(2\text{-}12)$$

Assuming that the Sherwood number remains constant, the final equation for scaling-up has the form

$$\frac{M_1}{M_2} = \left(\frac{H_1}{H_2}\right)^{0.69} \left(\frac{D_{c1}}{D_{c2}}\right)^{1.31} \left(\frac{d_{p2}}{d_{p1}}\right) \quad \ldots(2\text{-}13)$$

Figures 4 and 5 are parametric plots of this equation for particle diameter ratios of 1 and 0.53.

2.3 Comparison of Scale-Up Equations

The results of scale-up to a 12t/d spouted bed gasifier P.D.U. from models of diameter 0.305 and 0.150 m are compared in Table 1. Four different scale-up equations are compared using two distinct experimental reactors (in operation at U.B.C.) as models. The table

gives the diameter of the scale-up prototype, D_{c2}. The consistency of predictions by each of these equations can be estimated by comparing the scale-up diameter obtained by using model 1 and model 2. The variations are within 10% for equation (2-13), whereas scale-up by equation (2-8) results in about 40% deviation. Thus, Uemaki-Kugo equation is the preferred design equation. Detailed design of the P.D.U. is presented in Chapter 4. Figure 6 shows schematic of a spouted bed gasifier scaled-up by dimensionless analysis method.

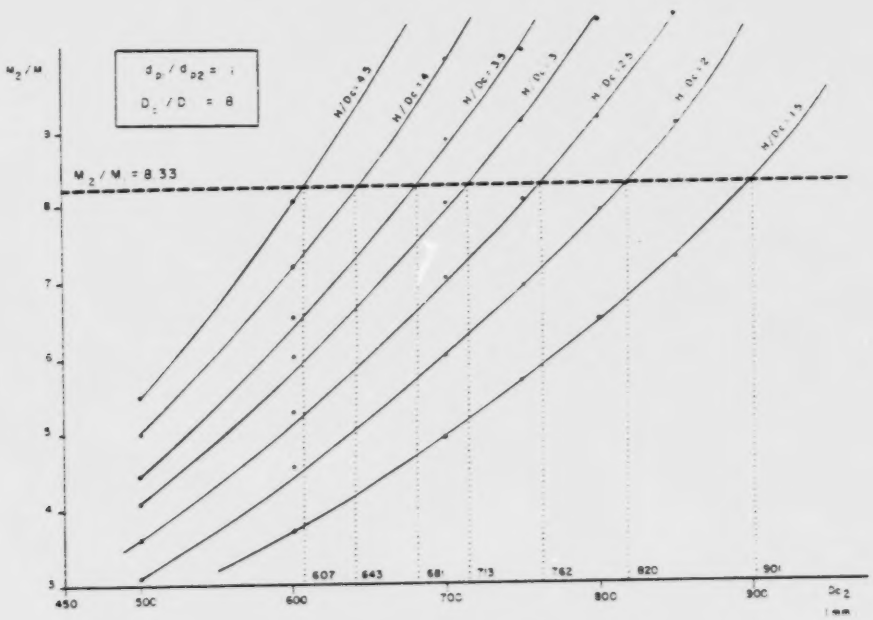

FIGURE 4. SCALING-UP BY UEMAKI-KUGO EQUATION (2-9) FOR 3.36 MM COAL.

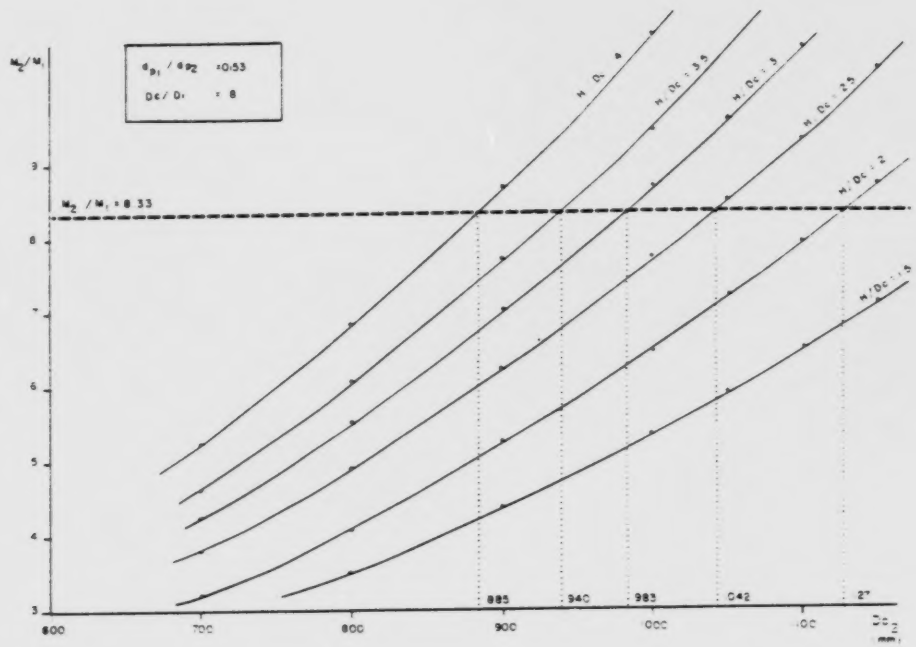

FIGURE 5. SCALING-UP BY UEMAKI-KUGO EQUATION (2-9) FOR 6.35 MM COAL.

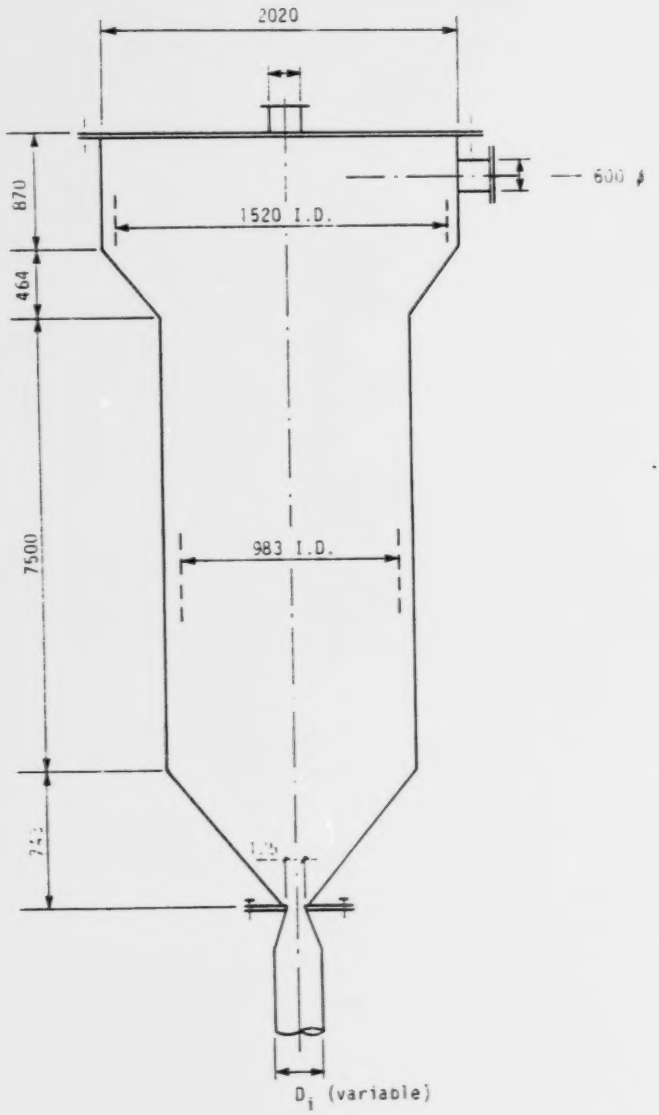

FIGURE 6. DIMENSIONS OF GASIFIER OBTAINED FROM SCALING-UP BY DIMENSIONLESS ANALYSIS METHOD.

TABLE 1

SCALING-UP OF GASIFIER DIAMETER

USING FOUR DISTINCT NON-DIMENSIONAL

EQUATIONS FOR TWO DIFFERENT MODELS

SCALE-UP EQUATIONS	REF. NO.	PROTOTYPE DIAMETER, D_{c2}, (m)	
		MODEL 1	MODEL 2
$U_{ms} = \left(\frac{d_p}{D_c}\right) \left(\frac{D_i}{D_c}\right)^{1/3} \left[2gH \left(\frac{\rho_p}{\rho_g} - 1\right)\right]^{0.5}$	13	1.13	1.678
$U_{ms} = \left(\frac{d_p}{D_c}\right) \left(\frac{D_i}{D_c}\right)^{0.23} 2gH\left[\left(\frac{\rho_p}{\rho_g} - 1\right)\right]^{0.5}$	10	0.902	1.335
$k_m = \frac{7.2U(Re)^{-0.43}}{\varepsilon_a (Sc)2/3}$	14	1.440	3.400
$\frac{k_m d_p}{D_v} = 0.00022 \left(\frac{d_p U_s \rho_g}{\mu_g}\right)^{1.45} \left(\frac{D_c}{H}\right)$	13	0.820	0.892

Where for Model 1 the column diameter is 0.305 m, inlet diameter is 0.0318 m, and bed height is 0.5 m. For Model 2 the values of these parameters are 0.15 m, 0.0191 m, and 0.25 m, respectively. For the prototype the, H/D_c, ratio is 2, and d_{p2}/d_{p1} equals unity.

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3.0 MATHEMATICAL MODELING

3.0 MATHEMATICAL MODELING

3.1 General

A proper understanding of the mass, momentum, and energy transport inside a chemical reactor is essential in order to design a reactor which performs according to the specifications. The factors affecting the operation of any chemical process can be studied by using the fundamental principle of conservation of mass, momentum, and energy. These concepts when expressed mathematically simulate the hydrodynamics and kinetics of a chemical process. Such a set of equations will predict the profiles of velocity, temperature, and concentration of various chemical species in the system.

The general scheme of developing a mathematical model is illustrated in Figure 7. The generalized equations of conservation of mass, momentum, energy, and chemical species are modified by using appropriate coordinate system, assumptions, and approximations to obtain constitutive equations. These equations along with the phenomenological information model the chemical reactor. This set of constitutive equations is then solved using analytical or numerical methods. The solution is transformed into a simulator - a computer program in one of the scientific-programming languages. The simulator can then be used to synthesize inputs such as operating conditions, physical properties, transport properties, and kinetic data to prognosticate the performance of a chemical reactor. This procedure was used here to develop a mathematical model of the spouted bed gasifier.

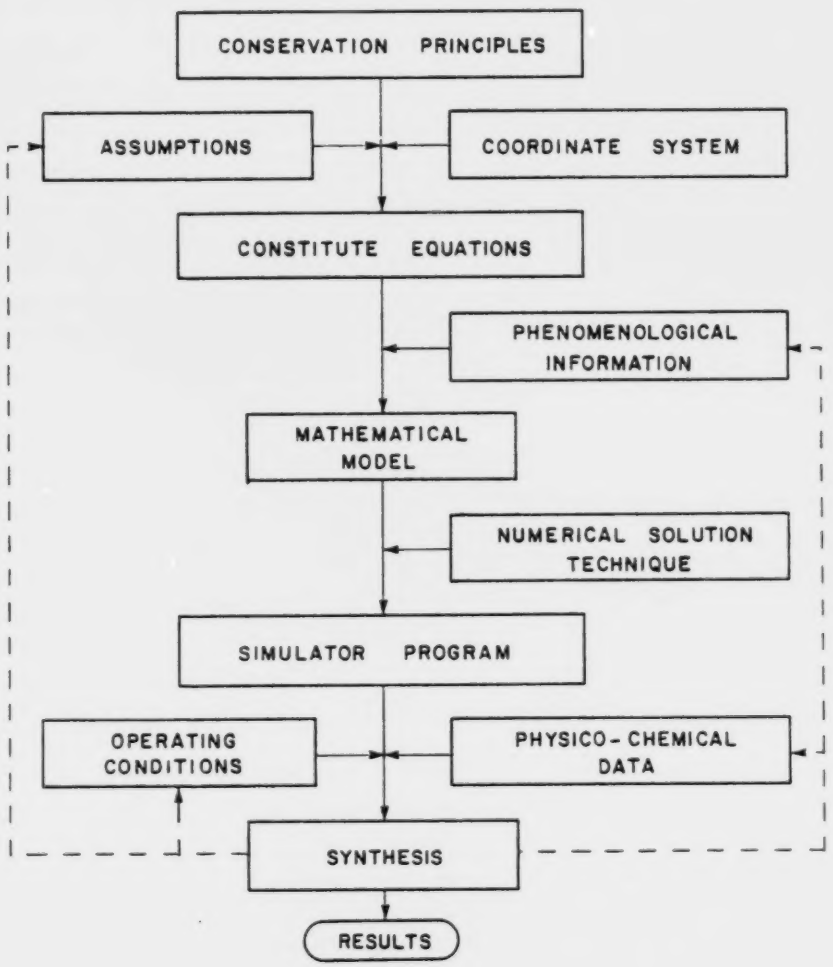

FIGURE 7. A SCHEME FOR MATHEMATICAL MODEL DEVELOPMENT.

3.2 Assumptions and Approximations

A number of assumptions and approximations are necessary to make a complex real system amenable to representation by a set of differential equations. These assumptions define important process variables and the scope of application of the model. The assumptions and approximations included in this model are outlined here.

It is assumed that the solid phase is well distributed, that is, there is no agglomeration of solids (coal and ash) in either the annulus or the spout. The size distribution of particles is uniform and the shape of an average particle is approximately spherical. This assumption defines the particle shape factor to be unity. The annulus is a uniformly packed bed of solids with a constant voidage. The interparticle forces are small at the spout-annulus interface where momentum is transferred by collisions between the bed surface and entrained particles in the annulus. The radial movement of particles at any given level is constant and directly proportional to the downward velocity of particles at that level. There is no axial dispersion of particles in the spout. The vertical component of the total pressure on the annular bed is proportional to the radial component. The particle velocity in the annulus is a function of the minimum spouting velocity, particle Reynolds number, bed height, reactor diameter, and bed voidage. A change in the temperature of the bed does not have noticeable effect on the physical and transport properties of the solids. Heat transfer due to conduction between solids and reactor wall, and gases and reactor wall will be neglected.

The gaseous phase in both the spout and the annulus is in the plug flow regime. Radial gradients in temperature and velocity are small. The axial diffusion of gases (particularly in the annulus where complicated fluid flow patterns cause gases to move in either direction) is neglected. There is bulk movement of gases between the annulus and the spout. The "end effects" at the entrance and the top of the spout are neglected. The spout diameter is constant while the spout voidage is a function of bed height only.

The fluid in the annulus obeys Darcy's law. The interzone mass transfer coefficient, the gas-solid heat transfer coefficients, and reaction rate constants are extrinsic. The gas phase obeys ideal gas law and Newton's law of viscosity. The properties of the gas phase can be approximated by the properties of air at average reaction temperature.

Finally, the equations are developed for steady state (time invariant) operations. The frame of reference is in the cylindrical coordinate system and there are no angular forces.

3.3 Constitutive Equations

The equations representing mass, momentum, and energy balances are developed on an element of the reactor shown in Figure 8. With the help of the assumptions and approximations the conservation principle can be applied on this reactor element to yield the following set of differential equations.

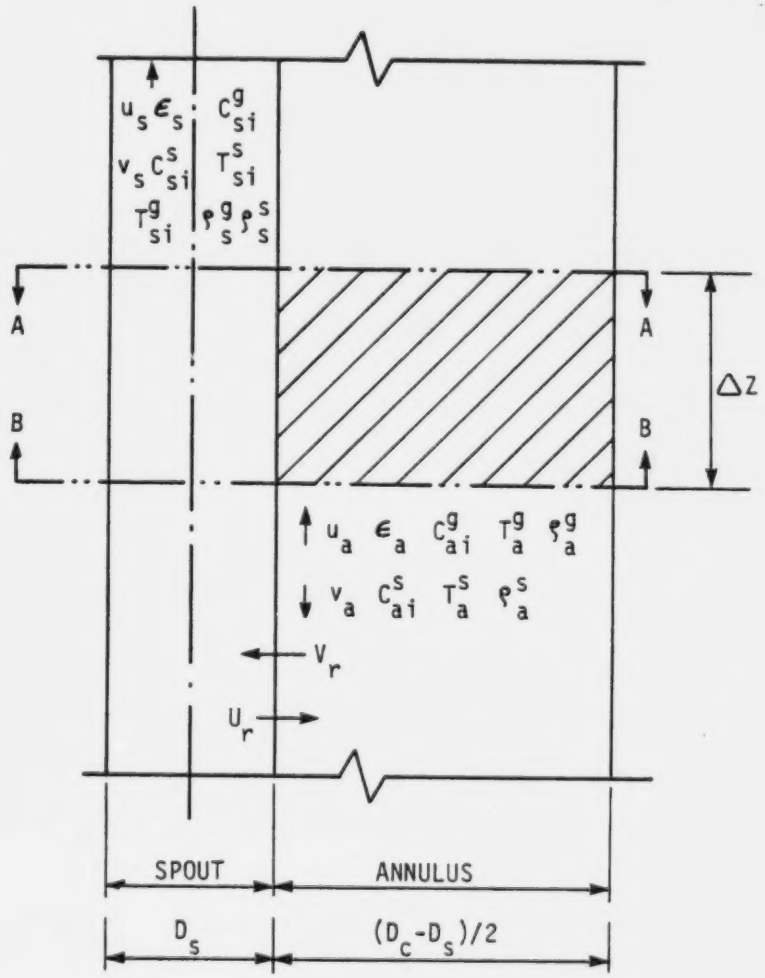

FIGURE 8. A SCHEMATIC REPRESENTATION OF THE CROSS-SECTION OF A SPOUTED BED REACTOR ELEMENT.

An inventory of mass, momentum, energy, and chemical species can be stated as:

OUTPUT - INPUT + LOSS - GENERATION = ACCUMULATION ...(3-1)

This principle of conservation is applied to both the spout and the annulus, and in each of these zones it is applied to both the gas and the solid phase. An example of the application of this principle for obtaining constitutive equations is given in Appendix A.

The conservation of gaseous species in the spout is:

$$\frac{d}{dz}\{C^g_{si} u_s \varepsilon_s\} - R^g_{si}(1-\varepsilon_s) + \frac{4}{D_s} C^g_{si} U_r$$

$$+ \frac{4}{D_s} k_{mi}\{C^g_{si} - C^g_{fi}\} = 0 \qquad \ldots(3\text{-}2)$$

In this equation, R^g_{si}, the net rate of change in the concentration of the species, i, is given by Arrhenius type reaction rate constants.

$$k_\ell = A_\ell \exp(-E_\ell / R_g T) \qquad \ldots(3\text{-}3)$$

where, ℓ, denotes a chemical reaction.

The conservation of solids in the spout is expressed by:

$$\frac{d}{dz}\{C^s_{si} v_s (1-\varepsilon_s)\} - R^s_{si}(1-\varepsilon_s)$$

$$\frac{-4}{D_s} C^s_{ai} (\varepsilon_s - \varepsilon_a) \frac{(1-\varepsilon_s)}{(1-\varepsilon_a)} V_r = 0 \qquad \ldots(3\text{-}4)$$

In the annulus the balance equation for gaseous species is:

$$\frac{d}{dz}\{u_a \varepsilon_a C^g_{ai} A_a\} - R^g_{ai} A_a (1-\varepsilon_a) - \pi D_s U_r C^g_{si}$$

$$- \pi D_s k_{mi} (C^g_{fi} - C^g_{ai}) = 0 \qquad \ldots(3\text{-}5)$$

A balance on solids in the annulus is given by:

$$\frac{d}{dz}\{v_a A_a C^s_{ai}\} + \pi D_s C^s_{ai} \frac{(\varepsilon_s - \varepsilon_a)}{(1-\varepsilon_a)^2} \frac{(1-\varepsilon_s)}{} V_r$$

$$- R^s_{ai} A_a = 0 \qquad \ldots(3\text{-}6)$$

The overall material balance in the reactor is:

$$\rho^g_s u_s \varepsilon_s A_s + \rho^s_s v_s (1-\varepsilon_s) A_s + \rho^g_a u_a \varepsilon_a A_a$$

$$+ \rho^s_a v_a (1-\varepsilon_a) A_a = \text{Constant} \qquad \ldots(3\text{-}7)$$

Thus, equations (3-2) through (3-7) represent the species and mass conservation for each of the phases in the spout and the annulus.

As in the case of the mass flowing through the system the momentum flowing through the reactor is conserved. Hence, equation (3-1) can be applied to the momentum of each of the phases.

Within the spout the upward flow of gases creates a pressure gradient which supports the annulus and causes leakage of gases across the spout-annulus interface. It has been assumed that the gas and solid velocities are uniform and the spout voidage is constant in any horizontal section. The momentum balance on the gaseous phase is the sum of pressure and drag forces (3):

$$\frac{d}{dz}\{\rho_s^g u_s^2 \varepsilon_s\} + \frac{4}{D_s} \rho_s^g U_r^2 + \frac{d}{dz} (\varepsilon_s p) + \beta(u_s^2 - v_s^2) = 0 \qquad \ldots(3\text{-}8)$$

For the solid phase the rate of change of momentum in the spout is given by the pressure forces due to the spout gases, the buoyancy forces, and the drag forces:

$$\frac{d}{dz} \rho_s^s v_s^2 + \frac{dP}{dz} + (\rho_s^s - \rho_s^g)g - \beta \frac{(u_s^2 - v_s^2)}{(1-\varepsilon_s)} + \frac{4 \rho_a^s V_r^2}{D_s(1-\varepsilon_s)} = 0 \qquad \ldots(3\text{-}9)$$

A similar approach fails to yield satisfactory representation of the momentum balances in the annulus due to the highly complex hydrodynamics in that zone. Mamuro and Hattori (12) have attempted to analyze the forces acting on the gases flowing through the annulus for an isothermal, non-reacting bed of solids spouted by gases. Based on their analyses they suggest the following correlation for gas velocity at any distance, z, from the inlet:

$$U_a = U_{mf} [1 - (1 - z/H_m)^3] \qquad \ldots(3\text{-}10a)$$

The relation has been tested for many gas-solid systems (13). Epstein, Lim, and Mathur (6) suggested that the boundary condition, $U_a = U_{mf}$, should be changed to, $U_a = U_{aH_m}$, when $z = H_m$. the resultant equation,

$$U_a = U_{aH_m} [1 - (1 - z/H_m)^3] \qquad \ldots(3\text{-}10)$$

is used in the present model.

Thorley et al. found that the downward particle velocity in the annulus varies marginally from particle velocity near the wall (13). The following empirical correlation was obtained by Abdelrazek (1):

$$v_w = U_{ms} \left[\exp\left(7.8748 \times 10^{-4} \, Re_p \frac{H}{D_t} - 3.5529\right)\right. \quad \ldots(3\text{-}11)$$

It correlates the data obtained by Abdelrazek on glass microspheres, and the data obtained by Thorley et al. (1,13) on wheat beds in 15.2 and 61.0 centimeter diameter vessels with a 60° conical base. The bed heights varied from 30.5 cm to 183 cm and the inlet diameter was between 1.25 cm and 10.2 cm. This correlation is used for the downward particle velocity in the annulus.

The sum of the convective energy exchanges between the spout gases and the entrained particles, the spout gases and the annular bed, the heat generated by reactions, and the energy lost by gases percolating across the spout-annulus interface gives an energy balance for gases in spout:

$$\hat{C}_p^g \frac{d}{dz}\left\{\rho_s^s \varepsilon_s u_s T_s^g\right\} - \frac{4}{D_s} h_{as} \left(T_a^s - T_s^g\right)$$

$$+ \frac{4}{D_s} U_r \rho_s^g C_p^g T_s^g - \frac{6\phi}{d_p} (1-\varepsilon_s) h_s - \left(T_s^g - T_s^s\right)$$

$$- \left(-\Delta H\right)_{rxn}^g R_s^g (1-\varepsilon_s) = 0 \qquad \ldots(3\text{-}12)$$

The spout solids interchange energy with the spout gases. There is an addition of energy generated by reaction as well as the energy of annular solids entering the spout, therefore, the energy balance for the spout solids is:

$$\hat{C}_p^s \frac{d}{dz}\{\rho_s^s v_s (1-\varepsilon_s) T_s^s\} - (-\Delta H)_{rxn}^s R_s^s (1-\varepsilon_s)$$

$$- \frac{6\phi}{d_p} (1-\varepsilon_s) h_s (T_s^g - T_s^s)$$

$$- \frac{4}{D_s} V_r \rho_a^s \hat{C}_p^s (\varepsilon_s - \varepsilon_a) \frac{(1-\varepsilon_s)}{(1-\varepsilon_a)} T_a^s = 0 \qquad \ldots(3\text{-}13)$$

Similar to the energy balance for gases in the spout, the following equation results from an inventory on convective exchanges between the particles and the annular gas:

$$\hat{C}_p^g \frac{d}{dz}\{\rho_a^g \varepsilon_a u_a T_a^g\} - (-\Delta H)_{rxn}^g A_a (1-\varepsilon_a) R_a^g$$

$$- \frac{6\phi}{d_p} A_a (1-\varepsilon_a) h_a (T_a^s - T_a^g) - \pi D_s U_r \rho_s^g \hat{C}_p^g T_s^g = 0 \qquad \ldots(3\text{-}14)$$

The energy balance for the annulus particles is the sum of the energy generated by the reaction, the energy lost to the spout gases, the energy lost to the annulus gases, and the energy lost by bulk flow of particles from the annulus to the spout:

$$\hat{C}_p^s \frac{d}{dz}\{\rho_a^s A_a v_a T_a^s\} + \frac{6\phi}{d_p} A_a h_a (T_a^s - T_a^g)$$

$$+ \frac{\pi D_s h_{as}}{(1-\varepsilon_s)} (T_a^s - T_s^g) + \frac{\pi D_s}{(1-\varepsilon_a)^2} (\varepsilon_s - \varepsilon_a)(1-\varepsilon_s) V_r \rho_a^s T_a^s$$

$$- (-\Delta H)_{rxn}^s R_a^s A_a = 0 \qquad \ldots(3\text{-}15)$$

Equations (3-2) through (3-15) describe the spouted bed gasifier. These equations are incomplete without a model for the chemical reactions occurring in the reactor.

3.4 Kinetic Model

There are several studies on the reaction mechanism in coal gasifiers (18), but there is a lack of relevant literature on spouted bed coal gasifier. This reactor cannot be modeled on the same lines as a fixed bed gasifier or a fluidized bed gasifier. As the model does not attempt to analyse the progress of a single particle through the reactor, the intrinsic mechanism of gas-particle interaction is of little importance. The following kinetic model is proposed.

(1) $C + CO_2 \xrightarrow{R_1} 2CO - \Delta H_1$

(2) $CO + \frac{1}{2} O_2 \xrightarrow{R_2} CO_2 + \Delta H_2$

(3) $C + O_2 \xrightarrow{R_3} CO_2 + \Delta H_3$

(4) $C + H_2O \xrightarrow{R_4} CO + H_2 - \Delta H_4$

$$(5)\quad C + 2H_2O \xrightarrow{R_5} CO_2 + 2H_2 - \Delta H_5$$

where, R_1 to R_5, are the net forward reaction rates expressed by a set of Arrhenius parameters, and reactant concentrations. These are global rates based on volume or surface area. Though most of the investigators have found it difficult to isolate the effects of reactor hydrodynamics and obtain rates for individual reactions, Angus and co-workers (2) have developed a scheme for estimating coal reactivities at practical operating conditions.

The rate constants for reactions (1) and (4) are obtained from their work on Montana Rosebud char and Illinois No. 6 char in thermogravimetric hanging basket reactor. The rate constants for reaction (2) and reaction (3) are obtained from Shadman and Cavendish (15). The reaction rates and heats of reactions are given in Appendix B.

3.5 Summary of the Mathematical Model

In addition to the kinetic rates it is essential to obtain information on the spout diameter, the maximum spoutable bed depth, the minimum superficial gas velocity for spouting, the spout voidage, the total pressure, heat transfer coefficients, mass transfer coefficients, and physical properties. This information is given in Appendix C. The minimum spouting velocity, U_{ms}, is obtained from the Mathur-Gishler equation (equation 2-2).

The set of differential equations (3-2) to (3-6), equations (3-8) and (3-9), equations (3-12) to (3-15), the kinetic model, equations (3-7), (3-10) and (3-11), and the correlations given in Appendix C constitute the mathematical model of a spouted bed coal gasifier. Equations (3-2) to (3-6) have to be written for each of the gaseous and solid species present in the reactor.

The kinetic model applies to five species, C, CO, CO_2, H_2O and H_2. Apart from these there are three other species which are considered "inerts" N_2, Ar and ash. Thus, there are eight species, which means that the model has a total of twenty-four species balance equations, four momentum equations, four energy equations, an overall mass balance equation, and a differential equation for spout voidage and spout pressure drop.

3.6 Numerical Solution

There exist several methods for numerically integrating a set of coupled ordinary differential equations (11) such as Euler's method, Runge-Kutta methods, and several multi-step integration methods such as Milne's methods, and Adams-Moulton method. Gill's modification of the fourth-order Runge-Kutta single step method minimizes the number of intermediate values to be stored during computations. It also minimizes the growth of the round-off errors without increasing the computation time. This method is used in the integration of the model equations. The fourth-order Runge-Kutta-Gill procedure is as follows:

Let, $$\Psi_j \equiv \Psi_j(\Theta, \Psi, \ldots \Psi_n, \Psi_1', \ldots, \Psi_n', \ldots) \qquad \ldots(3\text{-}16)$$

where, j, represents the number of dependent variables, then a system of ordinary differential equations can be developd such that,

$$\frac{d\Psi_j}{d\Theta}_{\Theta_r, \Psi_{jr}} \equiv \Omega_j(\Theta_r, \Psi_{jr}, \ldots), \Psi j \qquad \ldots(3\text{-}17)$$

Such a set of equations can be integrated over the interval $a \leq \Theta \leq b$ if the initial values of dependent variables, Ψ_j, are known. Hence, for an intergration step size of δ, the Runge-Kutta-Gill procedures gives:

$$\tau_{ji} = \delta\Omega_j \left[\Theta_r, \Psi_{jr}\right] \qquad \ldots(3\text{-}18)$$

$$\tau_{j2} = \delta\Omega_j \left[\Theta_r + \frac{\delta}{2}, \Psi_{jr} + \tau_{j1}/2\right] \qquad \ldots(3\text{-}19)$$

$$\tau_{j3} = \delta\Omega_j \left[\Theta_r + \frac{\delta}{2}, \Psi_{jr} + (-1/2 + 1/\sqrt{2})\,\tau_{j1} + (1 - 1/\sqrt{2})\,\tau_{j2}\right] \qquad \ldots(3\text{-}20)$$

$$\tau_{j4} = \delta\Omega_j \left[\Theta_r + \delta, \Psi_{jr} - \frac{\tau_{j2}}{\sqrt{2}} + \left(1 + \frac{1}{\sqrt{2}}\right)\tau_{j3}\right] \qquad \ldots(3\text{-}21)$$

$$\Psi_{jr+1} = \Psi_{jr} + \frac{1}{6}(\tau_{j1} + \tau_{j4}) + \frac{1}{3}\left(1 - \frac{1}{\sqrt{2}}\right)\tau_{j2} + \frac{1}{3}\left(1 + \frac{1}{\sqrt{2}}\right)\tau_{j3} \qquad \ldots(3\text{-}22)$$

The single step methods have three different types of error which decrease the accuracy of integration at every step. These include:

1. The local truncation error of the integration formula itself resulting from the use of an approximate equation to represent the real function.

2. The round-off error involved in the numerical implementation of the integration formula.

3. The inherited errors made in proceeding from θ_a to θ_r.

It is not possible to monitor each of these errors individually. Generally, the total error is an order of magnitude lower than the local truncation error of the integration procedure. The fourth-order Runge-Kutta process has a local truncation error of the order of δ^5 (i.e. $0(\delta^5)$) and an overall truncation error of $0(\delta^4)$. Thus an automatic error-monitoring scheme is devised to control the step-size, δ. The accumulated round-off error is decreased by carrying out the computations with 15-digit accuracy and limiting the overall accuracy of results to 10^{-4} percent.

The constitutive equations (3-2) to (3-15) along with the empirical equations given in Appendix C and the kinetic data given in Appendix B have been converted to a set of numerical expressions using the Runge-Kutta-Gill technique (equations (3-16) to (3-22)). The resultant expressions have been solved numerically on a digital computer. The computer program given in Appendix I thus simulates a spouted bed coal gasifier conforming to the assumptions and approximations associated with the mathematical model. The simulator predicts the axial profiles of the velocity, temperature, and composition of both gas and solid phase in each of the two hydrodynamic regions, namely, the spout and the annulus.

3.7 Results and Discussion

The simulator program requires initial values of the dependent variables, physical property data, and information regarding reactor characteristics in order to simulate the performance of a spouted bed coal gasifier. Sample data are given in Appendices C, and D. The simulation based on these input data varies from the experimental exit concentration by about 20%. The main reason for this discrepancy is the lack of accurate experimental data for each of the dependent variables.

The researchers at the University of British Columbia were able to provide some of the necessary design data such as the type of coals used, coal composition, exit-gas composition, reactor dimension, feed rates, and a range for reaction temperatures. Axial temperature profiles were provided for two runs. But some critical data were not available such as the inlet gas and solid temperatures, gas velocities in the spout and at the top of the annulus, gas and solids composition at the bottom and the top of the bed, gas composition in spout, pressure drop profile, rate of solid down-flow in the annulus, spout voidage, minimum spouting velocity, and maximum spoutable bed depth.

Another gray area is the lack of consistent kinetic data. One of the most important aspect of reactor modeling is reliable chemical kinetic data. Unfortunately, the researchers at the U.B.C. had not obtained this data. It is well known that coal reactivities change with the type of coal, the pretreatment of coal and even with the seam from which it is mined. It is well known that the carbon-oxygen reactions are faster than $C-CO_2$, $C-H_2O$ reactions by several orders of magnitude. This causes stiffness of the differential equations. The experimental values for various reactions have been obtained from diverse sources, therefore, the combination of reaction rate constants may cause

unforeseen problems. This has prompted a parametric study with different rate constants to match the experimental results, but the process is time consuming and costly.

There are a few other factors such as the constants in some of the empirical correlations which are being analyzed to see their impact on the synthesis of inputs. The accuracy of predicted results will improve if these empirical equations are replaced by fundamental equations, but, this will require futher analysis and substantial testing. Such a task can be undertaken when the physico-chemical data are sufficient and reliable thus leaving the model to account for any discrepancies between experimental and simulated results. Complex fundamental analysis might also be replaced by empirical correlations derived from experiments with the laboratory scale and pilot plant scale spouted bed coal gasifiers.

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4.0 DESIGN OF THE GASIFIER

4.0 DESIGN OF THE GASIFIER

4.1 Design of the Process Development Unit

The Spouted Bed Gasifier Process Development Unit is designed by scaling up the experimental reactor presently in operation at the Chemical Engineering Department of the University of British Columbia. The design has taken into consideration mass and energy balances presented by Watkinson et al. (20) and it is based on analogies with Winkler gasifier as described by Dibbs and Marier (5).

The P.D.U. has been designed for operation with air and steam as well as oxygen and steam. It will be operated using a variety of coals for gathering the necessary data for the design of a commercial unit. The P.D.U. will be used to investigate the gasification/combustion of various types of coal under different operating conditions including bed depth, temperture, pressure, and feed compositions.

Based on the dimensional analysis, the gasifier diameter for a height to diameter ratio of 3 is 0.983 meter (see chapter 2).

This ratio is less than the ratio of maximum spoutable bed depth to diameter. The maximum spoutable bed depth was obtained from equation (C-1) for a particle diameter of 6.35 mm (1/4"). This particle size has been specified in the statement of work in the contract. The spouted bed gasifier is capable of handling a wide range of coal particles. Based on the limited amount of experimental data collected at the University of British Columbia, it has been suggested that the gasifier be operated with larger particles (7). In the preliminary design the feed size has been limited to -6.35 mm to +1.00 mm.

For a given minimum spouting velocity, the maximum spoutable bed height increases with a decrease in particle size and inlet diameter. But experimental results indicate (13) that this trend reverses after a certain particle size is reached because the bed porosity decreases with particle size thus increasing bed density. The maximum spoutable bed depth, H_m, for particles of an average size of 3.36 mm is 5.8 m when the inlet diameter, D_i, is 0.10 meter.

Furthermore, when equation (2-1) is used to determine the rate of coal conversion the results indicate that for a spouted bed gasifier of diameter 1.0 m and inlet diameter 0.125 m optimum gasification condition will occur in a bed of height 3.2 m or 0.55 H_m when average particle size is 3.36 mm. This condition is obtained when the bed consists of 60% inerts. The experimental gasifiers at the U.B.C. are operated with less than the maximum spoutable bed depth, thus, this deduction could not be verified from available experimental data. The P.D.U. is designed to overcome this shortcoming. The designed height of the P.D.U. is 9.8 m including the disengagement section. Hence, it is possible to experiment with a bed of over 6.5 m in height, which is greater than the maximum spoutable bed depth of 5.8 m.

The gasifier is designed to operate both with bottom feeding and top feeding. Experimental work at the University of British Columbia indicates that bottom feeding minimizes the amount of tar in the gaseous product (6, 7, 20). It is hypothesized that this is a direct effect of the rate of devolatilization of coal. Coal devolatilizes rapidly at temperatures above 600°C. In the case of bottom feeding the volatile products are released at the bottom of the reactor and they undergo extensive combustion during their progress through the bed while in the case of top feeding the volatile matter is released in the relatively cooler

product gases above the bed. As most of the coal-tar is also released during devolatilization bottom feeding will increase the combustion of tar products while top feeding will shorten tar combustion time. But, in either case, combustion proceeds for sufficient time thereby diminishing the problem of tar condensation in transport lines.

The P.D.U. has been designed for a fountain height of 0.25 H. In order to decrease a carry-over of coal fines the gasifier will be provided with a deflector of controllable height that can be adjusted to suit the bed depth. The upper part of the gasifier is widened to decrease the velocity of exit gas and to prevent the carry-over of coal particles larger than 1 mm. Coal fines and ash will be collected in the cyclones and recycled to the bed at a height of 1.00 m above the bottom tangent line. The gasifier is completely lined on the inside wall by an insulation block and cast-in refactory so that the temperature of external wall does not exceed 70°C. The thickness of insulation layer was calculated on the basis of data given by Heilingenstaedt (8). In addition will also be insulated on the outside by 50 mm thick fiberglass wrapped in stainless steel sheathing for protection of plant personnel.

For experimental purposes the gasifier has been provided with 6 openings for the pyrometers for the measurement of the bed temperatures. The gasifier is also equipped with 12 temperature sensors. One temperature sensor is provided for controling feed stream temperature. Provision has been made for measuring pressure drop at various levels in the bed. Flow measurement elements are also provided for the measurement of gas velocity in spout. Additional ports will be provided for gas and solid sampling. The details are shown on Drawing number 6521-0000-49DD-003 Rev. PC.

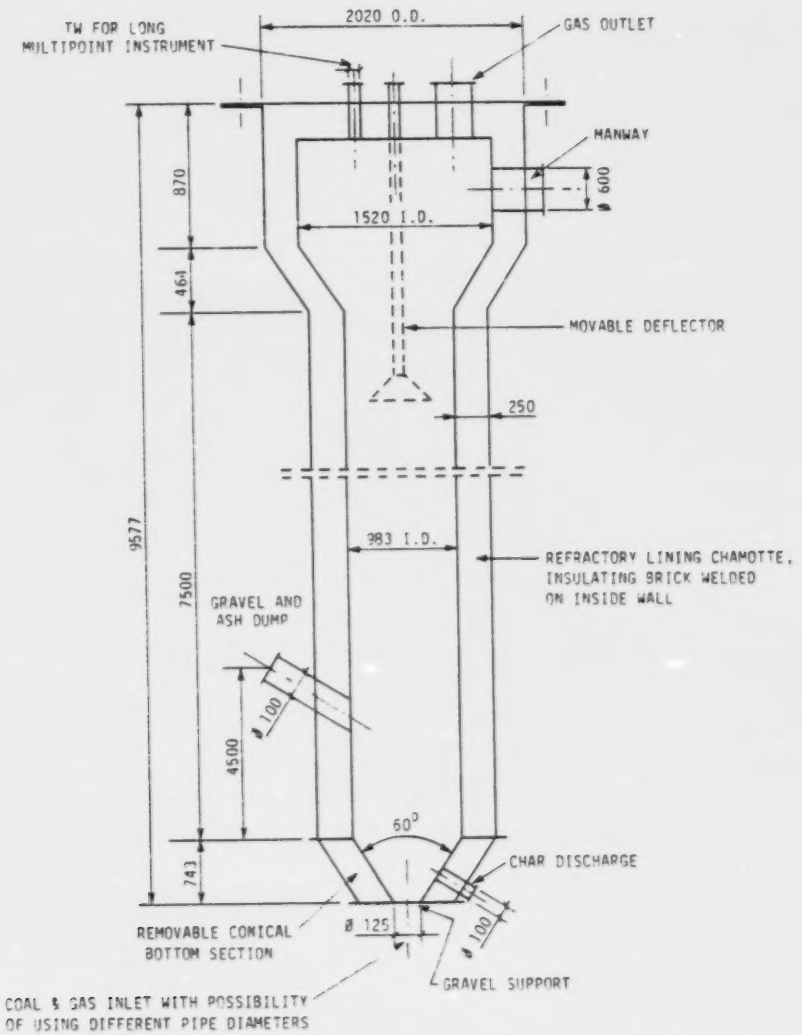

FIGURE 9. BASIC DESIGN SKETCH

4.2 Mass and Energy Balances

The mass and energy balances for the spouted bed gasifier are based on the work of Watkinson et al. (20) and on analogies with Winkler gasifier (5). Two different operating conditions have been considered, one with air and steam and the other with oxygen and steam.

In order to maintain kinetic similarity between the experimental unit at the University of British Columbia and the P.D.U. it is necessary to have the same coal throughput and gasifying-medium/coal ratio although the operating conditions for the two reactors may be different. This difference in operating conditions will be greater when oxygen-steam mixture is used as gasifying medium but the spouted bed gasifier makes it possible to work in a broad range of the operating conditions and with different feeds. Tables 2 and 3, respectively, give the mass-energy balances for operation with air-steam and oxygen-steam feed mixtures. The expected product gas compositions for these cases. The analysis given in Tables 2 to 5 is based on gasification of Forestburg coal (16). This mass and energy balances are based on Watkinson's work at U.B.C. (20).

Hence, based on the dimension less analysis given in Chapter 2, the dimensions of a 12 tonne dry coal per day Process Development Unit spouted bed gasifier are (see Gasifier Vessel drawing 6521-45DD-003 Rev. PC):

Internal Diameter	1.0 m
Vessel Height	9.8 m
Inlet Diameter	0.3 m

These dimensions may not conform to the preferred fabrication dimensions. The detailed engineering of the P.D.U. vessel will be in vendor-preferred dimensions.

TABLE 2

MASS AND ENERGY BALANCES
FOR AIR AND STEAM FEED

STREAM		MASS FLOW (kg/h)	ENERGY FLOW (MJ/h)
INPUT:	Coal	500	12,557
	Air	1516	
	Steam	228	11
	TOTAL	2244	12,568
OUTPUT:	Char	34	507
	Gas	2176	11,289 (c 8,745)
	Dust in Gas	28	409
	Tar	4	150
	TOTAL	2242	12,355
	LOSSES		1.6%

TABLE 3

MASS AND ENERGY BALANCES
FOR OXYGEN AND STEAM FEED

STREAM		MASS FLOW (kg/h)	ENERGY FLOW (MJ/h)
INPUT:	Coal	500	12,557
	Steam	2500	123
	Oxygen	378	
	TOTAL	1872	12,680
OUTPUT:	Char	7	104
	Gas	1833	11,745 (c 9,332)
	Dust in Gas	28	409
	Tar	4	150
	TOTAL	1872	12,408
	LOSSES		2.1%

TABLE 4

PREDICTED PRODUCT GAS
COMPOSITION FOR AIR-STEAM FEED

COMPONENTS	% WEIGHT	% VOLUME
CO_2	21.8	12.7
CO	16.4	15.2
H_2	1.3	16.4
CH_4	0.7	1.1
N_2	59.6	54.4

TABLE 5

PREDICTED PRODUCT GAS
COMPOSITION FOR OXYGEN-STEAM FEED

COMPONENTS	% WEIGHT	% VOLUME
CO_2	41.5	20
CO	49	37
H_2	3.5	37
CH_4	2	3
N_2	4	3

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5.0 AUXILIARY SYSTEMS

5.0 AUXILIARY SYSTEMS

5.1 Coal Handling

The coal handling system is designed to minimize cost, maintenance and handling time. A bag house dust collection system is provided to eliminate dust emission at transfer points and bins. Fire protection will be provided in the form of hydrants, stand pipe, and fire-hose stations throughout the plant. The plant layout will be reviewed and adjusted once the site is selected.

The main design criteria are as follows:

- All equipment are located above grade.
- Coal will be reclaimed at an average rate of 40 tonnes per hour and a maximum rate of 80 tonnes per hour.
- Coal rail car will be unloaded by means of a Clamshell bucket of 4-5 cubic yard capacity.
- Coal handling equipment for unloading coal from rail cars, reclaiming coal, and carrying coal to the 40 tonne bin shall be selected on a minimum-overall-cost basis due to the short life of the installation and its noncommercial character.
- Coal handling rate from the bin discharge, crushing, bucket elevator, and screen shall be 11 tonnes per hour. The filling time for the 10 tonne crushed-coal bin will depend on the amount of coal rejected (-1 mm to +6.4 mm) from the total "as received" quantity coal fed to the unit per day (12 to 20 t/d).
- The annual coal throughput will be between 3000 to 4000 tonnes based on an average of 12 tonnes per day of dry coal (up to 5% moisture coal). Lignite has to up 40% total moisture, subbituminous coal to up 30% total moisture.

Therefore, 12 tonne of dry coal equals 20 tonnes of lignite with 40% moisture or 17 tonnes of subbituminous coal with 30% moisture.

It has been assumed that coal will arrive in 100 ton goldola (open top) rail cars or trucks. Coal will be removed by Clamshell bucket on a mobile crane from the rail cars and stock-piled or dumped on the ground from trucks. This method will be reviewed when the plant site is agreed upon. If a site is selected near the waterfront it might be possible to receive coal in barges. Space has been provided for three 150 t piles (three distinct types of coal may be stock piled simultaneously). These piles will be built with the Clamshell crane. Coal will be transferred with a front-end loader to a 40 t bin at a rate of 40 t/h via a feed hopper and conveyor. This 40 t bin would require filling every 2 to 3 days, depending on the type of coal stored. A bin bag dust collection system is mounted on top of the bin. It also acts as dust collector for the rest of the system. The maximum size of "as received" coal is expected to be about 100 mm. The layout of the coal handling system is shown on Drawing 6521-0000-45DD-002 Rev. PB.

As shown in Process and Instrument Diagram (Drawing number 6521-0000-49DD-001 Rev. PC) coal will be transferred from the 40 t bin at a rate of 12 t/h and crushed to about -6.4 mm (after removal of tramp iron by a magnetic separator). The crushed coal is fed to a bucket elevator which discharges to a double-deck screen. Coal is screened to feed only the -6.4 mm to +1.0 mm size to the process. The +6.4 mm coal is sent to a reject bin together with the -1.0 mm coal and disposed of as waste or sold. Due to the small amount of coal involved it is not economical to use the fines as fuel in this installation.

The screened coal is fed to a 10 tonne crushed-coal bin which serves as a day-bin and requires filling once or twice a day. A "loss in weight" type of weighfeeder delivers coal to the P.D.U. from the day bin. This method is preferred in small scale operations. The feeder has its own electronic control/recording system to enable feeding from 500 to 1500 kg/h.

The weighfeeder discharges through a small chute to the air-lock feeder. The air-lock feeder is set to feed the maximum amount of coal delivered by the weighfeeder. The rotary air-lock valve and downstream pipeline up to the gasifier are to be stainless steel because oxygen will be used for transporting coal when operating with oxygen-steam mixture. The transport air shut-off valve, check valve and related interconnecting and downstream piping are also to be stainless steel as they may come in contact with oxygen.

Coal is mixed with the air stream and fed to the gasifier after the gravel bed has attained a predetermined temperature. The coal-feed pipe is isolated from the inner surface of the gasifier (and flame) by a ceramic nozzle designed to keep the temperature of the stainless pipe below 300°C.

5.2 Gas Cleaning

Two stainless steel cyclones will be used in series to remove char and ash from the product gas. The gas is then routed to a heat exchanger to generate process steam. About 228 kg/h of steam is required when operating with air. The heat exchanger is used as a steam generator for this amount of steam. Steam requirements will increase to about 2500 kg/h when oxygen is used as gasifying medium instead of air.

The product gas will be used to fire the auxilliary steam boiler (to generate 2500 kg steam/h). This will require a special medium BTU gas burner equipped with a natural gas pilot burner.

5.3 Operation with Air

Air is used to transport coal and gravel. The gravel bed is preheated to 425°C by using natural gas. Thereafter, only coal and air are supplied to the gasifier. Transport air is supplied from a pressure blower delivering air at 0.15 MPa. A second blower supplies preheated air from a refractory lined burner box (via a stainless steel pipe concentric to the coal supply pipe) to the gasifier ceramic nozzle. Steam is mixed with the preheated air downstream of the burner box. The details are shown in the Process and Instrument Diagram (Drawing number 6521-0000-49DD-001 Rev. PC).

5.4 Operation with Oxygen

Commercial oxygen will be used instead of air for a certain number of campaigns. Ten tonnes of oxygen will be used per day along with upto sixty tonnes of steam. The bulk of this steam will be used to replace the air formerly used for spouting purposes. Dry steam mixed with oxygen in the ratio 1:3 is to be used for transporting coal. The air blower will be isolated by a stainless steel check valve and a shut-off valve. Oxygen will be supplied from a 35 tonne cryogenic bulk supply tank located on the property. The tank is supplied by the oxygen manufacturer complete with a vaporizer, valve train, and pressure reducing station. The stainless steel piping from the pressure reducing station to the P.D.U. complete with the shut-off control valves and instruments will be supplied as part of the P.D.U. plant.

It was estimated that the plant would operate a total of 100 days per year with oxygen using 10 tonnes per day or 1000 tonnes per year.

5.5 Steam Generation

228 kilograms per hour of steam is required for operation with air and this amount can easily be produced from the heat exchanger/steam generator utilizing the hot product gases.

This unit is shown in the Process and Instrument Diagram, (Drawing number 6521-0000-49DD-001 Rev. PC). On the other hand, 2500 kg/h of steam will be required when operating with oxygen. A packaged steam boiler will be used for this purpose. This boiler will be located in the service building described separately. In the future the product gas could be used to generate this steam using a special burner. A deaerator has been incorporated in system design to remove dissolved air from boiler feed.

5.6 Incinerator System

When operating with air, a gas of low calorific value is produced. This gas will be burned in an incinerator with a designed capacity of 10 MJ/h. The flue gas will be evacuated by a tall chimney as shown in the Process and Instrument Diagram (Drawing Number 654-000-49DD-001 Rev. PC). This incinerator will also burn the higher calorific value gas (upto 10 MJ/m^3) produced when operating with oxygen. In the future this heat may be recovered through the auxiliary steam boiler to produce the 2500 kg/h of steam required for gasification with oxygen.

5.7 Service Building and Facilities

The entire P.D.U. spouted bed gasifier plant including the coal handling system will be built outdoors. However, a 10 m x 25 m by 4 m high building will be provided to house an office (4.5 x 5.0 m), conference room (4.5 x 5.0 m) a laboratory (3.5 x 4.0 m), a boiler room and laydown area (10.0 x 10.0 m), workshops and washrooms (5.0 x 5.0 m), and electrical and control room (5.0 x 5.0 m), as shown on Drawing 6521-0000-45DD-002 Rev. PB.

Plant Fire Protection will be by hydrants located within the property for the coal piles and within the plant area itself with hose stations supplied by stand pipes at various locations such as the Spouted Bed Gasifier, level, top of bins, and near as well as within the service building. Suitable fire protection of a dry type will be provided for the electrical and control room, and work shop areas.

All construction will conform to the local, provincial, and federal fire prevention and construction codes. The gas and electrical systems will be built to the British Columbia Hydro and to other applicable standards.

5.8 Plant Layout

The plant covers an area of 66 metres by 103 metres as shown on the P.D.U. Spouted Bed Gasifier General Arrangement Diagram (Drawing number 6521-000-45DD-002 Rev. PB). This includes a railroad spur which can hold two to three rail cars of 100 tonnes, space for three distinct coal piles of 150 tonnes each, ground level conveyor to the 40 tonne day-bin, and the plant complete with the service building. The plant is built entirely

out of doors with the exception of the office, laboratory, conference room, cafeteria and recreational area, product gas boiler, and laydown area for large pieces, workshop and electrical control room, all of which is enclosed in a service building 10 m x 25 m. Space is provided for parking and access roads. The plant layout will be reviewed and reorganized as necessary to suit the actual site chosen for this project.

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6.0 INSTRUMENTATION

6.0 INSTRUMENTATION

The instrumentation of the Process Development Unit is designed to achieve the following goals:

- Aquisition of sufficient data to design a commercial plant.
- Control the plant operations over a large spectrum of operating conditions.
- Safety.

6.1 Aquisition of Design Data

As the main purpose of a process development unit is to acquire data which will aid in designing a commercial scale reactor the process instrumentation will monitor and record important operating parameters such as temperature, pressure and flow rates throughout the plant. Instrumentation will also yield radial and axial temperature profiles of the spouted bed). Apart from the process parameters operation of the P.D.U. will provide design data such as material analysis for coal, ash, feed gases and product gases either continuously or periodically. All these data can be acquired either manually, semi-automatically, or by a minicomputer as desired.

6.2 Control of Plant Operations

In any chemical plant instrumentation is designed to carry out safe and efficient plant operation. This is achieved by monitoring and manipulating critical operating variables such as feed rates of various reactants, temperatures, pressure, etc. There are 9 control loops in the preliminary design:

Weighfeeder - Equipped with weight indicator and controller for measuring and controlling coal feed.

FIC - 109 - Automatic air to pneumatic transport regulator with flow indication and automatic blower speed changer.

FIC - 111 - Automatic oxygen to pneumatic transport regulator and flow indicator.

FIC - 113 - Automatic air to burner regulator with flow indication and automatic blower speed changer.

FFRC - 125 - Steam/oxygen flow-ratio controller with one pen to record flow-ratio.

FIC - 302 - Automatic steam to gasifier regulator and flow indicator.

FIC - 311 - Automatic steam to gasifier regulator and flow indicator.

PIC - 310 - Automatic steam pressure (in steam drum) controller with output to the control valve located on heat exchanger bypass line.

LIC - 306 - Automatic water level (in heat exchanger) controller and level indicator with output to the control valve located on water supply line.

In addition, there are several HIC loops that allow manual control of the entire plant from the control room, especially during start-up and shut-down periods.

6.3 Safety

Several alarm devices have been provided for safe operation of the P.D.U. gasifier. These are LSAH-101, LAL-102, LAH-103, LAL-104, FAL-109, PSAH-107, BIXA-121, TIAHL-201, LSAHL-307, and BIXA-316. A relief valve, RV-216, is provided at the gasifier outlet to prevent explosion due to any sudden rise in vessel pressure. Another relief valve, RV-323, will protect the steam drum. The steam/oxygen flow ratio controller, FFRCAL-125, will

maintain their flow rates within predefined limits, and thus, minimize the probability of formation of explosive gaseous mixtures in the gasifier. It will also prevent the coal/oxygen ratio in transport lines from reaching the autoignition limits.

In case of a pressure build-up in the pneumatic transport lines, caused for example by coal deposits, the weighfeeder will be automatically stopped and alarm will be triggered in the control room by the high pressure switch, PSAH-107. An air blower failure will be immediately signaled by the FAL-109 system in the control room. Thus, the plant operator will have an opportunity either to start (automatically) the air blower and the burner in another air-feed-to-gasifier line to keep the bed spouting and hot, or to shut down the unit. Temperature in the spouted bed gasifier will be monitored by TIAHL-201 system with an alarm for high and low temperature levels. If the normal product gas route is blocked there will be a sudden rise in reactor pressure causing the relief valve, RV-216, to open and draw excess gases to the stack. Composition of the product gases will be monitored both periodically (for some special analyses) and continuously by chromatographic methods.

The details of instrumentation are shown on the P&I Diagram (Drawing 6521-0000-49DD-001 Rev. PC).

FORM 512(B)
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7.0 SAFETY AND ENIVRONMENTAL PROTECTION

7.0 SAFETY AND ENIVRONMENTAL PROTECTION

7.1 Plant Operations

A process development unit is designed to operate over a wide range of process conditions. This raises the question of operational safety. Several problems are anticipated in the operation of the spouted bed gasifier and the following solutions are suggested to overcome these difficulties

Explosion of Gaseous Mixtures:

The gasifier produces carbon monoxide, hydrogen, methane, and heavier hydrocarbon gases. These gases may cause explosions if there is a leak in the product gas lines and the concentration of any of these gases lies in the explosive limits.

The autoignition limits of some of the products are: hydrogen 4.1 and 74.2, carbon monoxide 12.5 and 74.2, and methane 5.3 and 13.9 percent by volume in air. Thus, explosion vents will be provided in the lines and frequent monitoring of product gas composition will give an operator sufficient time to minimize the danger and damage.

Coal Handling:

Coal dust may cause explosions in grinding equipment when the high temperatures are reached. Explosions and fires may be initiated by static electricity discharges, hot surfaces and spontaneous combustion. This problem is encountered only when the concentration of coal dust in air lies within the explosion limits. Isolating the coal handling utility, removal of foreign magnetic materials and use of inert gases such as carbon dioxide,

nitrogen or flue gases decreases the danger. Explosion vents will be provided in the grinding and coal handling equipment such as the bag house. Above mentioned precautionary measures are also recommended.

Clogging of Coal-Feed Line:

An alarm has been included in the control loop for the coal feed blower. This alarm will alert the plant operator in the event of a sudden failure of the pneumatic coal transport system. The plant operator can then take corrective action such as providing heated air to maintain bed temperature or purge the gasifier of its solids and stop operations. Details of the later manoeuvre have not been specified in this preliminary design.

Clogging of Heat Exchanger Tubes:

As the heat exchanger providing process steam utilizes the product gases its tubes may get clogged by the fly ash (although the amount of fly ash produced by a spouted bed is extremely small to create such a problem). In such an event the flue gas stream will be diverted directly to the incinerator which is designed to burn high calorific gases (10 MJ/m^3) and the auxiliary steam generator brought online to provide process steam.

Steam:

The experiments will be carried out with a wide range of steam/air and steam/oxygen ratios and the heat exhcanger is designed to provide the necessary process steam for campaigns with air as the gasifying medium. If for any reason the steam demand is not met by the heat exchanger the auxiliary steam generator will be immediately brought on stream to fulfill these requirements. If the

steam input decreases drastically the gasifier will mainly produce CO_2 thus decreasing the danger of explosion or fire hazard. The steam generator and drum are fitted with pressure release valves, to prevent a blow up.

7.2 Fire Protection Facilities

Both the plant and the service building will have numerous fire hydrants and a stand pipe as well as alarm system which can alert personnel working in any part of the plant. Dry and chemical-foam fire fighting equipment will also be included. The fire fighting equipment will confirm to local, provincial and federal regulations.

7.3 Safety of Personnel

Plant personnel will be provided necessary industrial hygiene and safety facilities such as rest area, personal safety shower, first-aid kit, protective headgear, and eyeglasses. The service building will be isolated from the plant by a fire protection wall. Plant equipment, piping, and electrical power lines will be well insulated. The service building will have emergency exits to facilitate immediate evacuation in case of a fire inside the building. The personal safety measures will be based on guidelines provided by regulations covering occupational hazards and safety.

7.4 Environmental Protection

The Process Development Unit is going to be used intermittently during its design life of three years. When in operation, it will process on an average 12 tonnes of dry coal per day. Thus, the emission of air pollutants such as NO_x and SO_x will be

small and costly pollution control equipment should not be installed in the system. The main air pollutants are coal dust, fly ash, and char particles in the flue gases. The coal dust fines will be trapped using a baghouse. Fly ash and char in the flue gases will be removed by two cyclones operating in series. The stack gases will be periodically monitored for NO_x and SO_2 levels. Disposal of fly ash, char, and coal fines will depend on plant location.

FORM 111(B)

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8.0 PRELIMINARY ESTIMATE

8.0 PRELIMINARY ESTIMATE

8.1 Capital Cost

The preliminary capital cost for the 12 tonnes dry coal per day Process Development Unit Spouted Bed Gasifier is 1,850,000 dollars including 15% for contingencies. The estimated direct cost is 1,327,700 dollars and the estimated service cost is $265,500. The basis and details of this estimate are given in Appendices F and G, respectively.

8.2 Operating Costs

The cost of operating this facility on the basis of three shift operation is estimated to be 1,500,000 dollars per annum. This estimate includes salaries, benefits, and overhead charges for an engineer and seven plant personnel, cost of raw materials, land lease charges, cost of utilities, cost of rented equipment, maintenance and miscellaneous subcontract work. The breakdown of the operating cost is given as follows:

Breakdown of Operating Cost

	Description	Operating Cost, $/Annum
1	Labour	626,000
2	Raw Material (Including Coal)	400,000
3	Utilities	150,000
4	Land Lease	50,000
5	Rental Payment for Equipment	100,000
6	Maintenance and Site upkeeping	100,000
7	Miscellaneous Subcontract Work	74,000
TOTAL		1,500,000

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MONTRÉAL QUÉBEC

9.0 SITE SELECTION

9.0 SITE SELECTION

9.1 Selection Criteria

A total of six sites were investigated for locating the process development facility designed here. The following criteria were used in evaluating these sites:

1) the space available,
2) the facilities available (water, power, etc.),
3) availability of skilled labor on a sub-contract basis,
4) transportation facilities for bringing the coal in,
5) environmental considerations.

9.2 Sites

All the sites are located in the proximity of Vancouver, British Columbia. A brief description of each of the six sites is presented in an increasing order of preference.

Robert's Bank Coal Port:

This is an isolated industrial area and has the advantage of having millions of tonnes of coal. There would not be any environment related complaints if the plant was installed here. The main disadvantages of this location are that it is extremely congested, water is scarce, and it would be difficult to get a skilled instrument mechanic on sub-contract.

Neptune Terminals:

Located in the northern Vancouver, Neptune Terminals is a highly congested industrial facility. Although this site has the advan-

tage of having millions of tonnes of coal, it has the same disadvantages as Robert's Bank Coal Port and it will not be possible to establish a P.D.U. at this site.

Canadian Occidental Petroleum and Erco Chemicals:

These are small chemical plants having ample space just outside their fence. They are located about three kilometers to the east of Neptune Terminals in North Vancouver. Canadian Occidental produces caustic, chlorine, and hydrochloric acid. This plant has about 30 acres of flat enclosed space. Erco manufactures sodium chlorate and has about 15 acres outside their fence. Their plant is located about five hundred meters to the east of Canadian Occidental. Some advantages of locating the P.D.U. here are availability of water and electricity, and security. It would also be easy to get an instrument mechanic on sub-contract.

The problem is that the District of North Vancouver has rezoned this area to limit any new chemical plants in the area. In essence, these two plants now cannot use that vacant land to expand their facilities. About a quarter of a mile away, behind a field of trees, there is a residential community and the District of North Vancouver fears that the chemical plants may pollute air, causing danger to these residents. The management of the two chemical plants stated that they were considering fighting the new zoning regulations in the courts, but they advised us that they did not think it would be practical for us to build a P.D.U. there.

Annacis Industrial Estate:

There is ample space on this estate located on the Annacis Island in the Fraser River. The advantages of this site are an existing

rail spur and availability of water and electricity. There is no chemical plant on the island and it would be difficult to sub-contract for an instrument mechanic. There probably would be no problem from the environmental point of view but there are houses on the bank across the river about a kilometer away.

Duke Point Industrial Park:

Duke Point Industrial Park is located eight kilometers from the City of Nanaimo, B.C. It has been created by a joint effort of the Federal Department of Regional Economic Expansion and the British Columbia Department of Industry and Small Business Development under the auspices of the Canada/B.C. Industrial Developments Subsidiary Agreement. It is a newly developed facility having two deep sea wharves and two floating barge terminals which can be used to bring the coal into the plant. Water and electric utilities will be shortly available. About a kilometer away there is a caustic-chlorine plant operated by Canadian Occidental and a paper mill operated by Harmac Pulp and Paper. This area is zoned for heavy industry. This location seems to have all the facilities required for the operation of the P.D.U.

Hence, it is recommended that the P.D.U. be constructed on Duke Point Industrial Park. Some literature on this site is attached.

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10.0 CONCLUSIONS

10.0 CONCLUSIONS

The spouted bed reactor may prove to be an innovative and elegant system for gasifying and combusting a large variety of raw materials such as bituminous and subbituminous coals, lignite, and even wood. As the spouted bed reactor operates at atmospheric pressure and gasifies larger particles than either fluidized bed, entrained bed, or ebulated bed gasifier it will prove to be a cost effective energy conversion system. The crushing, grinding, and gas cleaning steps of a gasification process are energy intensive and the capital costs are also significant. Additional benefits will results from low char/coal carry over, no slagging, and the ability of gasifying coals with higher Free Swelling Index.

The design data obtained from the experimental reactor at the University of British Columbia are not sufficient for designing a commercial scale reactor. In order to achieve the goal of commercializing the spouted bed gasifier further developmental work has to be carried out in a pilot plant scale process development unit. The objective of this study was to determine the feasibility of designing such an unit based on the work done at the University of British Columbia.

A pragmatic reactor scale-up procedure has been successfully implemented. Based on the work presented in the previous chapters it is concluded that a Process Development Unit can be designed, constructed, and operated to evaluate important process parameters for a spouted bed gasifier.

A conceptual design of the facilities to operate 12 tonne dry coal per day P.D.U. has been prepared, this includes, coal preparation and handling, gas cleaning, steam generation, oxygen supply, gas incineration, systems, building and site facilities and utilities. A possible site for locating the PDU has been identified. An order of magnitude estimate of the capital and operating costs has been prepared. Furthermore, a mathematical model has been developed to simulate a spouted bed gasifier. This model was tested using the available information which was necessary but not sufficient. Thus, it is difficult to evaluate the results predicted by this model until further developmental work is carried out.

FORM 620(B)?
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MONTRÉAL, QUÉBEC

11.0 RECOMMENDATIONS

11.0 RECOMMENDATIONS

This feasibility study shows that it is possible to design a process development unit to assess the potential of a spouted bed gasifier. As this is an intermediate step on the way to commercialization of the Spouted Bed Gasifier Technology, it is recommended that the project team should immediately proceed with detailed design, engineering, procurement, and construction of the Process Development Unit. It is further recommended that all efforts be made to improve the simulator program. This would also require additional experimental data. Such data can be obtained both from the P.D.U. and the bench scale unit at the University of British Columbia.

The data collected from the operation of the prototype together with the available data from the model can be used to design a commercial spouted bed reactor for gasification/combustion of diverse solid fuels (such as bituminous and subbituminous coals, lignite, and wood) to produce synthesis gas and/or gaseous fuels.

NOMENCLATURE

NOMENCLATURE

Roman Letters

A - Area, m^2

A - Frequency factor for Arrhenius rate constants.

B_p - Constant.

C - Concentration, kg/m^3

C_p - Specific heat, kJ/kg. K

D - Diameter, m

D_v - Diffusion coefficient, m^2/s

d - Diameter, m

E - Activation energy, kJ/k mol

G - Gas mass flow rate per unit column area, $kg/m_2.s$

g - Acceleration due to gravity, m/s^2

H - Height of bed, m

h_m - Maximum spoutable bed height, m

H - Heat of reaction ,kJ/kg

h - Heat transfer coefficient, $kJ/m^2.K.s$

K - Constant

k - Reaction rate constant

k_m - Mass tansfer coefficient, m/s

k - Thermal conductivity kJ/K.m.s

M - Material input, kg/h

M - Rate of char combustion, kg/h

n - Constant

p - Total pressure, Pa

R - Reaction rate, kg/m^3

R_g - Gas constant, kJ/kmol K

T - Temperature, K

NOMENCLATURE

U - Superficial gas velocity, m/s.

u - Interstitial gas velocity, m/s.

V - Superficial particle velocity, m/s.

v - Interstitial particle velocity, m/s.

z - Axial distance, m.

Greek Letters

β - Gas-solid interaction factor given by equation (C-9).

δ - Incremental axial distance, m.

λ - Shape factor of particle.

ε - Voidage.

Θ - Independent variable.

μ - Viscosity, kg/m·s.

π - 3.141592...

ρ - Density, kg/m^3.

τ - Interpolation variable.

ϕ - Shape factor.

Ψ - Dependent variable.

Ω - Derivative function of Ψ in Θ.

Superscripts

g - Gas phase, gaseous species.

s - Solid phase, solid species.

Subscripts

a - Annulus zone.

bf - Beginning of fluidization.

NOMENCLATURE

c - Column.

f - At the interface; fluidization condition; fluid.

g - Gas.

H_m - Maximum spoutable bed height.

i - Chemical species; inlet.

j - Equation identifier.

ℓ - Reaction identifier.

m - Maximum; minimum; mass transfer.

mf - Minimum fluidization condition.

ms - Minimum spouting condition.

p - Particle; constant pressure.

r - r^{th} value; radial direction.

rxn - Reaction.

s - Spout; solid.

T - Tube; cylinder.

tf - Total fluidization condition.

w - At the wall.

z - Axial direction.

1 - Model.

2 - Prototype.

Dimensionless Groups

N_{Ga} - Gallilio Number, equation (C-5).

Re_p - Particle Reynolds number, $\rho_g d_p U/\mu_g$.

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APPENDICES

LOVELL FORM A-610(D)
PROCÉDÉ Plasdex® PROCESS
MONTRÉAL, QUÉBEC

C B A

APPENDIX A

SPECIES BALANCE FOR SPOUT

APPENDIX A

SPECIES BALANCE FOR SPOUT

An inventory of any gaseous species flowing through the reactor element shown in Figure 8 is obtained by adding the following terms.

Input	$u_s \varepsilon_s A_s C^g_{si} \mid_z$	...(A-1)
Output	$u_s \varepsilon_s A_s C^g_{si} \mid_{z + \Delta z}$	...(A-2)
Generation	$R^g_{si} A_s (1-\varepsilon_s) \Delta z$	...(A-3)
Interzone Bulk Flow	$\pi D_s C^g_{si} U_r \Delta z$	...(A-4)
Interzone Mass Transfer	$\pi D_s \Delta z k_{mi} (C^g_{si} - C^g_{fi})$	...(A-5)
Diffusion: In	$-D_v A_s \varepsilon_s \left(\frac{dC^g_{si}}{dz} \right) \Big\vert_{z + \Delta z}$	...(A-6)
Diffusion: Out	$-D_v A_s \varepsilon_s \left(\frac{dC^g_{si}}{dz} \right) \Big\vert_{z}$	...(A-7)

Substitution of equation (A-1) to (A-7) for appropriate terms in equation (3-1), and division by $A_s \Delta z$ gives:

$$\frac{u_s \varepsilon_s C^g_{si}\Big|_{z+\Delta z} - u_s \varepsilon_s C^g_{si}\Big|_z}{\Delta z} - R^g_{si}(1-\varepsilon_s)$$

$$+ \frac{4}{D_s} C^g_{si} U_r - \left[\frac{D_v \frac{dC^g_{si}}{dz}\Big|_{z+\Delta z} - D_v \frac{dC^g_{si}}{dz}\Big|_z}{\Delta z}\right]$$

$$+ \frac{4}{D_s} k_{mi}(C^g_{si} - C^g_{fi}) = 0 \qquad \ldots(A\text{-}8)$$

Taking limits as $\Delta z \longrightarrow 0$, transforms equation (A-8) to:

$$\frac{d}{dz}(u_s \varepsilon_s C^g_{si}) - R^g_{si}(1-\varepsilon_s) + \frac{4}{D_s} C^g_{si} U_r$$

$$- D_v \frac{d^2 C^g_{si}}{dz^2} + \frac{4 k_{mi}}{D_s}(C^g_{si} - C^g_{fi}) = 0 \qquad \ldots(A\text{-}9)$$

As it is assumed that diffusion is negligible the last term in equation (A-9) is taken as zero. This assumption is valid for large-Reynolds-number reaction zones. In the spout the average Reynolds number is greater than 2300, hence, the species balance equation for spout gases becomes:

$$\frac{d}{dz}(u_s \varepsilon_s C^g_{si}) - R^g_{si}(1-\varepsilon_s) + \frac{4}{D_s} C^g_{si} U_r$$

$$+ \frac{4 k_{mi}}{D_s}(C^g_{si} - C^g_{fi}) = 0 \qquad \ldots(A\text{-}10)$$

B

C

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APPENDIX B

RATES OF CHEMICAL REACTIONS

APPENDIX B

RATES OF CHEMICAL REACTIONS

The following are the rate expressions for the reactions included in the kinetic model:

$$R_1 = A_1 \exp(-E_1/R_gT)[CO_2] \quad \ldots(B\text{-}1)$$

$$R_2 = A_2 \exp(-E_2/R_gT)[CO][O_2] \quad \ldots(B\text{-}2)$$

$$R_3 = A_3 \exp(-E_3/R_gT)[O_2] \quad \ldots(B\text{-}3)$$

$$R_4 = A_4 \exp(-E_4/R_gT)[H_2O] \quad \ldots(B\text{-}4)$$

$$R_5 = A_5 \exp(-E_5/R_gT)[H_2O] \quad \ldots(B\text{-}5)$$

The Arrhenius constants in equation (B-1) through (B-5) are given in Table 6. The reaction (2) occurs in the gas phase only while other reactions are considered to be surface reactions.

TABLE 6

REACTION RATE CONSTANTS

Reaction	Frequency Factor, A	Activation Energy E/R_g, ^oK	Heat of Reaction, kJ/kg *	Ref. No.
1	1.581×10^{11} (s^{-1})	30,196.28	-13,991.67	2
2	4×10^{15} $(kg^{-1}m^3s^{-1})$	15,028.41	10,092.00	15
3	1.536×10^{12} (s^{-1})	12,142.95	32,950.00	15,2
4	7.6585×10^{3} (s^{-1})	11,900	-11,308.33	2
5	6.5457×10^{3} (s^{-1})	11,900	- 8,826.667	19

* The heats of reactions area in kilojoules per kilogram of carbon except for reaction (2) for which the units are kilojoules per kilogram of CO.

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APPENDIX C

EMPIRICAL CORRELATIONS

APPENDIX C

EMPIRICAL CORRELATIONS

Maximum Spoutable Height of the Bed

$$H_m = 0.105 \times 10^{3.6} D_t^{2.15} d_p^{-0.75} D_i^{-0.4} \rho_p^{-1.2} \phi^2 \qquad \ldots(C\text{-}1)$$

This correlation was developed by Malek (13). It is a simple correlation though not very accurate at large values of D_t.

Spout Diameter

$$D_s = 0.118\ G^{0.49} D_t^{0.68} \rho_p^{-0.41} \qquad \ldots(C\text{-}2)$$

The correlation has been derived from experimental data on wheat, barley, millet rice, corn, flax, polyethylene, and polystyrene (13).

Minimum Fluidization Velocity

$$U_{mf} = 0.5\ (U_{bf} + U_{tf}) \qquad \ldots(C\text{-}3)$$

Vaid et. al. (17) observed that fluidization begins with finer particles at a velocity, U_{bf}. To fluidize larger particles a higher velocity, U_{tf}, is required. These velocities are obtained from Kunii and Levenspiel with Wen's approximation (17).

$$U_{bf} = \frac{\mu_g}{104 \rho_g d_p} \left[(1883^2 + 208\ N_{Ga}^2)^{0.5} - 1883 \right] \qquad \ldots(C\text{-}4)$$

$$N_{Ga} = \frac{d_p^3 \, g(\rho_p - \rho_g)\rho_g}{\mu_g^2} \qquad \ldots(C\text{-}5)$$

$$U_{tf} = \frac{0.5 \, \mu_g}{18.3 \, \rho_g d_p} \left(877^2 + 73.2 \, N_{Ga}^2\right)^{0.5} - 877 \qquad \ldots(C\text{-}6)$$

Pressure Drop

Lefroy and Davidson have observed that the pressure near the spout-annulus interface is a quarter-cosine curve (9),

$$P = \frac{2}{\pi} B_p \, \rho g H \, (1-\varepsilon_s) \cos \frac{\pi Z}{2H} \qquad \ldots(C\text{-}7)$$

Expression for β in equation (3-8)

The gas-solid interaction factor, β, is evaluated at particle fluidization condition, at which the buoyant force equals the pressure gradient. Thus, from equations (3-8) and (3-9),

$$\beta = \frac{\varepsilon_s}{u_s} (\rho_p - \rho_g)(1-\varepsilon_s)g \qquad \ldots(C\text{-}8)$$

Minimum Spouting Velocity (13)

The Mathur-Gishler equation (2-2) can be used to determine minimum spouting velocity. Uemaki and Kugo's correlation (equation 2-9) may also be used. The following equation is currently being tested in the mathematical model:

$$U_{ms} = 7.73 \, (\tan \gamma)^{0.72} \, (d_p/D_t)^{0.62} \times (D_i/D_t)^{0.155 \tan \gamma} (UHg)^{1/3} \qquad \ldots(C\text{-}9)$$

The coefficient of internal friction, tan γ, for coal is taken as 3.2. This correlation was obtained by Manurang (13) based on data obtained in a 0.15 m diameter column. The inlet diameter varied from 9 to 15.2 mm, and the base was made from a 60° cone. The experiments were carried out with coals of six different sizes, polystyrene, rape seed, and millet. The bed height varied from 0.2 to 1.0 m. This correlation is found to be particularly good for coal mixtures. In equation (C-9) U is obtained from modified Ergun's equation:

$$1.75\ \rho_g d_p U_{mf}^2 + 150\ (1-\varepsilon_a)\mu_g U_{mf} - d_p^2\ \varepsilon_a^3\ (\rho_p - \rho_g)g = 0 \qquad \ldots(C\text{-}10)$$

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APPENDIX D

INPUT TO SIMULATOR PROGRAM

APPENDIX D

INPUT TO SIMULATOR PROGRAM

Axial Distance, z, m	0.0
Reactor diameter, m	0.305
Inlet diameter, m	0.0318
Particle diameter, m	0.00336
Cone angle	60°
Bed voidage	0.42
Specific heat, particle, kJ/kg·K	0.295
Specific heat, gas, kJ/kg·K	1.077
Coal feed rate, kg/h	29.73
Air feed rate, kg/h	115.00
Steam feed rate, kg/h	10.20
Spout gas temperature, °C	100.0
Spout particle temperature, °C	50.0
Annulus gas temperature, °C	600.0
Annulus particle temperature, °C	605.0
Particle density, kg/m^3	1430.0
Viscosity of gas, kg/m s	4.246×10^{-5}
β_p	0.75
k_{mi}, s^{-1}	8.79×10^{-2}
R_g, kJ/kgmole K	8.31758

Coal Analysis [%] (20):

Carbon	66.79
Hydrogen	4.25
Ash + Sulfur	11.08
Oxygen	16.28
Nitrogen	1.60

Composition, kg/m^3	Spout	Annulus
Oxygen	0.1509	6.4457×10^{-2}
Carbon monoxide	0.0	10^{-14}
Carbon dioxide	3.5857×10^{-4}	1.5314×10^{-4}
Steam	5.7825×10^{-2}	2.4697×10^{-2}
Hydrogen	0.0	10^{-14}
Nitrogen	0.4923	0.21025
Argon	8.3906×10^{3}	3.5836×10^{-3}

PROCEDE Plasdex® PROCESS
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APPENDIX E

SPECIFICATIONS AND DATA FOR EQUIPMENT

SNC	MASTER EQUIPMENT LIST	CLIENT CANMET	CONTRACT 6521	SUBDIVISION	ELEMENT CODE	REVISIONS	NO	DATE	DESCRIPTION	BY	CHKD	APPD	PAGE 1 OF 4
		PROJECT PDU SPOUTED BED GASIFIER	MADE BY PR	APPD BY	DATE 82.06.04								

CODE	EQUIPMENT NO	QTY	DESCRIPTION	CAPACITY	SIZE	HP	MATERIAL	WEIGHT	SPECN NO	P.O. NO	REMARKS	REV
			MOBILE CRANE WITH									
	001	1	CLAMSHELL FOR RAIL CAR	40t/h	18.3m Boom							
			UNLOADING (30-40/YEAR)		3.7m^3 (3 Tonne)							
					CLAMSHELL BUCKET							
	003	1	CONVEYOR C/W TRAMP	80t/h	600mm x 36.6m	15						
			IRON MAGNET.		x 19m LIFT							
	004	1	FRONT END WHEEL		3.7m^3 BUCKET							
			LOADER									
	005	1	HOPPER AND GRIZZY	40 tonnes	4.6m x 4.6m x 6.5m	-						
	006,007	2	SCREW CONVEYOR	11t/h	400mm Φ 3.7m	3	MILD					
	008	1	SCREW CONVEYOR	11t/h			STEEL					
			(DUST COLLECTION)									
	009	1	HAMMERMILL CRUSHER	11t/h								
			MOTOR	-	1200RPM EXPL PROOF	50						
			V BELT	-	1:1 RATIO							
		1	BUCKET ELEVATOR	11t/h	(14"x 8"x 11^3/4"x 75')	10						
		1	SCREEN	11t/h	2 DECK (6mm, 1mm)	1 1/2						
					600 x 1200 mm							
			ENCLOSURE FOR ABOVE									
		1	HOPPER	10t	2400mm DIA,							
					x 3m HIGH							
					x 2.13m CONE							
					HEIGHT							

snc

MASTER EQUIPMENT LIST

CLIENT: CANMET

PROJECT: PDU SPOUTED BED GASIFIER

CONTRACT: 6521

MADE BY: PR

APP'D BY:

SUBDIVISION:

ELEMENT CODE:

DATE: 82.06.04

REVISIONS

NO	DATE	DESCRIPTION	BY	CHKD	APP'D

CODE	EQUIPMENT NO	QTY	DESCRIPTION	CAPACITY	SIZE	HP	MATERIAL	WEIGHT	SPEC'N NO	P.O. NO	REMARKS	REV
		1	WEIGH FEEDER ASS'Y C/W COAL SAMPLER	500 - 1500 kg/h								
		1	AIRLOCK STAR FEEDER 1 ADAPTERS & PIPING EL.	500 - 1500 kg/h		1	STAINLESS STEEL 304					
		1	BLOWERS ASS'Y AND PIPING	8.5 m^3/min TO 12.75 m^3/min @ 92 kPa		25	S.S. PIPING					
		1	BLOWER ASS'Y AND PIPING	8.5 TO 12.75 m^3/min @ 92 kPa		25	S.S. PIPING 304					
		1	BURNER ASS'Y : AIR/BED PRE-HEATER	4540 MJ/H								
		1	BURNER ASS'Y PRODUCED GAS INCINERATOR/BURNER	10550 MJ/H								
		1	CHAR/GRAVEL SAMPLER									
		1	GAS SAMPLER									
		2	CYCLONES 1-20" 2-16"	2163 kg/h @ 500°C /940°C 99.2 m^3/min			S.S. 310					

SNC

MASTER EQUIPMENT LIST

CLIENT: CANMET

PROJECT: PDU SPOUTED BED GASIFIER

CONTRACT: 6521

MADE BY: PR

SUBDIVISION:

APPD BY:

ELEMENT CODE:

DATE: 82.06.04

REVISIONS

NO	DATE	DESCRIPTION	BY	CHKD	APPR

CODE	EQUIPMENT NO	QTY	DESCRIPTION	CAPACITY	SIZE	HP	MATERIAL	WEIGHT	SPECN NO	P.O. NO.	REMARKS	REV
		1	REACTOR VESSEL		0.963m ID x 10m HIGH	-						
		LOT	GAS DUCTING	2163 kg @ 500°C /840°C			STAINLESS STEEL, 310					
		LOT	GAS DUCTING: CYCLONE TO HEAT EXCHANGER	2163 kg @ 430°C /820°C			STAINLESS STEEL					
		1	HEAT EXCHANGER UNFIRED STEAM BOILER GAS - TUBE SIDE WATER - SHELL SIDE		510mm DIA. x 7600 mm LONG (28.5m²)	-	MILD STEEL					
		1	STEAM DRUM	210 kg/h ITEM (min.)	900mm Φ x 6.1m		MILD STEEL					
		LOT	DUCTING - GAS HEAT EXCHANGER TO FAN				S.S. 304					
		1	FAN	0.66 m³/S 205°C & 3.6kPag								
			MOTOR			15						
		1	STACK		900 mm x 22000 mm	-						
		2	STEAM BOILER	2000kw (2500 kg/h)		200 BOILER HP						
			WATER TREATMENT									

SNC

MASTER EQUIPMENT LIST

CLIENT: CANMENT

PROJECT: PDU SPOUTED BED GASIFFIER

CONTRACT: 6521

MADE BY: PR

SUBDIVISION:

APPD BY:

ELEMENT CODE:

DATE: 82.06.02

REVISIONS

NO	DATE	DESCRIPTION	BY	CHKD	APPD

PAGE 4 OF 4

CODE	EQUIPMENT NO	QTY	DESCRIPTION	CAPACITY	SIZE	HP	MATERIAL	WEIGHT	SPECN NO	P.O. NO	REMARKS	REV
		1	OXYGEN BULK TANK & VAPORIZER & GAS TRAIN	32 TONNES LIQUID OXYGEN	3200 mm DIA 9500mm HIGH BASE x 9600mm x 9600mm x 450mm THICK (No.5 @ 300 cc)	-	R/CONC.	27.2 tonnes				
		1	DUST COLLECTOR BAG HOUSE C/W DUCTS	190 m^3/mn 5.5 : 1 AIR TO CLOTH RATIO								

REACTOR / CONVERTER

SPEC NO. 1

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION GASIFIER / OPERATING CASE: AIR + STEAM /		EQUIP. NO.	R-1
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY JP	CHECKED BY	APPROVED BY
	DATE 17/05/82	DATE	DATE

OPERATING DATA

STREAM: FEED/PRODUCT		COAL	AIR	STEAM	GAS		
PHASE		SOLID	GAS	GAS	GAS		
FLOW RATE	KG/HR	631	1516	97	2208		
TEMPERATURE	C°	15	15	132	865		
PRESSURE	ATA		1.3	1.3	1.1		
PRESSURE DROP							
COMPOSITION	%						

PROCESS LIMITATION ON WALL TEMPERATURE

TEMPERATURE/PRESSURE CYCLING

TOTAL HEATING OR COOLING LOAD /HR

METHOD OF HEATING OR COOLING

REACTION DATA: HEAT OF REACTION

EQUILIBRUM CONSTANTS

PHYSICAL DATA

DENSITY	t/m³	1.43	0.0014	0.0007	0.0003	
LATENT HEAT						
SPECIFIC HEAT	kcal/kg x °C				0.34	
VISCOSITY	cP					
CONDUCTIVITY						
MOLECULAR WEIGHT		12.0	29.0	18.0	25.2	

CATALYST DATA

SPECIFIC HEAT BTU/LB °F	ANGLE OF FRICTION	CAUSES OF DEGENERATION	
CONDUCTIVITY BTU/FT HR °F	VOIDAGE	REGENERATION	
CRUSHING STRENGTH	INT. ANGLE OF FRICTION	LIFE OF CATALYST	
BULK DENSITY LB/FT³	MANUFACTURER & NO.	CATALYST TYPE & SIZE	

ENGINEERING DATA

CORROSION

SUGGESTED MATERIAL OF CONSTRUCTION

SOLID DEPOSITION LIKELY

MAXIMUM PRESSURE 1.5 ATA LIMITED BY

MAXIMUM TEMPERATURE 1150 ° LIMITED BY

MINIMUM FLUID TEMPERATURE ° ASSOCIATED PRESSURE

INSULATION REQUIRED YES

PURPOSE OF INSULATION CHAMOTTE BRICK PLUS REFRACTORY BRICK

FIREPROOFING

MINIMUM BASE ELEVATION

IS EQUIPEMENT SUBJECTED TO MECHANICAL VIBRATION

EMERGENCY VACUUM DESIGN

BRANCH CONNECTIONS

ANY BRANCH CONNECTIONS TO BE PREPARED FOR WELDING

INTERNAL FITTINGS:

EXTERNAL FITTINGS:

SUGGESTED TYPE OF REACTOR/CONVERTER

OPERATING (HR/DAY)

REMARKS

ISSUED TO PROJECT GROUP DATE BY

REACTOR / CONVERTER

SPEC NO. 1a

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION GASIFIER / OPERATING CASE: OXYGEN + STEAM		EQUIP. NO.	R-1
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY IP	CHECKED BY	APPROVED BY
	DATE 17/05/82	DATE	DATE

OPERATING DATA

		COAL	OXYGEN	STEAM	GAS		
STREAM: FEED/PRODUCT							
PHASE		SOLID	GAS	GAS	GAS		
FLOW RATE	KG/HR	631	378	863	1865		
TEMPERATURE	C°	15	15	132	940		
PRESSURE	ATA		1.3	1.3	1.1		
PRESSURE DROP							
COMPOSITION	%						

PROCESS LIMITATION ON WALL TEMPERATURE

TEMPERATURE/PRESSURE CYCLING

TOTAL HEATING OR COOLING LOAD /HR

METHOD OF HEATING OR COOLING

REACTION DATA: HEAT OF REACTION

EQUILIBRUM CONSTANTS

PHYSICAL DATA

DENSITY	t/m³	1.43	0.0018	0.0007	0.0023		
LATENT HEAT							
SPECIFIC HEAT	kcal/kg x °C				0.33		
VISCOSITY	CP						
CONDUCTIVITY							
MOLECULAR WEIGHT		12	32	18	21.2		

CATALYST DATA

SPECIFIC HEAT	BTU/LB °F	ANGLE OF FRICTION	CAUSES OF DEGENERATION
CONDUCTIVITY	BTU/FT HR °F	VOIDAGE	REGENERATION
CRUSHING STRENGTH		INT. ANGLE OF FRICTION	LIFE OF CATALYST
BULK DENSITY	LB/FT³	MANUFACTURER & NO.	CATALYST TYPE & SIZE

ENGINEERING DATA

CORROSION

SUGGESTED MATERIAL OF CONSTRUCTION

SOLID DEPOSITION LIKELY

MAXIMUM PRESSURE	1,5 ATA	LIMITED BY	
MAXIMUM TEMPERATURE	1150 °C	LIMITED BY	
MINIMUM FLUID TEMPERATURE	°	ASSOCIATED PRESSURE	

INSULATION REQUIRED YES

PURPOSE OF INSULATION 1 CHAMOTTE BRICK + 1 REFRACTORY BRICK

FIREPROOFING

MINIMUM BASE ELEVATION

IS EQUIPEMENT SUBJECTED TO MECHANICAL VIBRATION

EMERGENCY VACUUM DESIGN

BRANCH CONNECTIONS

ANY BRANCH CONNECTIONS TO BE PREPARED FOR WELDING

INTERNAL FITTINGS:

EXTERNAL FITTINGS:

SUGGESTED TYPE OF REACTOR/CONVERTER

OPERATING (HR/DAY)

REMARKS

ISSUED TO PROJECT GROUP DATE BY

DATE MAR 77	REACTOR / CONVERTER PROCESS DATA SHEET	SNC	PR DSGN 114
REV			

PRESSURE VESSEL / TANK DATA

SPEC NO. 2

GENERAL

PROJECT NO. 6521	PLANT	SECTION	
FUNCTION OXYGEN TANK			EQUIP. NO. V-1
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY JP	CHECKED BY	APPROVED BY
	DATE 27/04/82	DATE	DATE

OPERATING DATA

SPECIFIC CAPACITY		M^3
VOLUME OF FLUID	1500	M^3
WEIGHT OF FLUID	10,000	KG
AGITATION		
SUGGESTED DIMENSIONS	SPHERE	M
OPERATING TEMPERATURE	20	°C
OPERATING PRESSURE	20	ATA
MAXIMUM FLUID TEMPERATURE		°C
HEATING / COOLING BY	USING AT	AND °C
FLASH POINT OF CONTENTS		

PHYSICAL DATA

DENSITY	0.59	T/M^3
SPECIFIC HEAT		
VISCOSITY		cP

ENGINEERING DATA

- CORROSION
- SUGGESTED MATERIAL OF CONSTRUCTION
- SOLIDS DEPOSITION LIKELY
- MAXIMUM PRESSURE — LIMITED BY
- MINIMUM FLUID TEMPERATURE — ASSOCIATED PRESSURE
- INTERNAL FITTINGS
- EXTERNAL FITTINGS
- INSULATION REQUIRED
- PURPOSE OF INSULATION
- ACCESS REQUIRED
- BRANCH CONNECTIONS
- ANY BRANCH CONNECTIONS TO BE PREPARED FOR WELDING
- SUGGESTED TYPE OF PRESSURE VESSEL/TANK
- OPERATING (HR/DAY)

REMARKS

ISSUED TO PROJECT GROUP — DATE — BY

PRESSURE VESSEL / TANK DATA			SPEC NO. 3
GENERAL	PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION
	FUNCTION STEAM DRUM		EQUIP. NO. V-2
	FLOWSHEET NO.	DESIGN BOOK NO.	
	CALC NO. PREPARED BY JP	CHECKED BY	APPROVED BY
	DATE 27/04/82	DATE	DATE

OPERATING DATA	SPECIFIC CAPACITY	6.2	M^3
	VOLUME OF FLUID	6.2	M^3
	WEIGHT OF FLUID	11.6	KG
	AGITATION		
	SUGGESTED DIMENSIONS	1.0 x 6.0	M
	OPERATING TEMPERATURE	138	°C
	OPERATING PRESSURE	3.5	ATA
	MAXIMUM FLUID TEMPERATURE	145	°C
	HEATING / COOLING BY USING AT AND		°C
	FLASH POINT OF CONTENTS		
PHYSICAL DATA	DENSITY	1.87×10^{-3}	T/M^3
	SPECIFIC HEAT		
	VISCOSITY		cP
ENGINEERING DATA	CORROSION		
	SUGGESTED MATERIAL OF CONSTRUCTION		
	SOLIDS DEPOSITION LIKELY		
	MAXIMUM PRESSURE 4.3 ATA LIMITED BY		
	MINIMUM FLUID TEMPERATURE ° ASSOCIATED PRESSURE		
	INTERNAL FITTINGS		
	EXTERNAL FITTINGS		
	INSULATION REQUIRED		
	PURPOSE OF INSULATION		
	ACCESS REQUIRED		
	BRANCH CONNECTIONS		
	ANY BRANCH CONNECTIONS TO BE PREPARED FOR WELDING		
	SUGGESTED TYPE OF PRESSURE VESSEL/TANK		
	OPERATING (HR/DAY)		
REMARKS	ISSUED TO PROJECT GROUP DATE BY		

DATE MAR 77	PRESSURE VESSEL / TANK PROCESS DATA SHEET	SNC	PR DSGN 118
REV			

HEAT EXCHANGER

SPEC NO. 4

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION HEAT EXCHANGER			EQUIP. NO. E-1
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY IP	CHECKED BY	APPROVED BY
	DATE 18/05/82	DATE	DATE

OPERATING DATA

		SHELL SIDE		TUBE SIDE	
HEAT LOAD	2,100 MJ/HR	IN	OUT	IN	OUT
INCL HEAT LOSS/LEAK	10 %				
FLUID CIRCULATED					
TOTAL FLUID RATE KG/HR		692		1839	1839
VAPOUR RATE KG/HR			692		
LIQUID RATE KG/HR		692			
NON-CONDENSABLES RATE KG/HR					1407
FLUID VAPORIZED/CONDENSED KG/HR		692			432
TEMPERATURE °C		15	138	907	80
OPERATING PRESSURE ATA			3.5		
ALLOWABLE PRESSURE DROP					
MAX FLUID TEMPERATURE °C			145	1000	

PHYSICAL DATA

		SHELL SIDE		TUBE SIDE	
DENSITY t/m^3		0.996	1.87×10^{-3}	0.00022	0.00073
SPECIFIC HEAT kcal/kg×°C		1.0		0.33	
LATENT HEAT			535		
VISCOSITY cP		0.8			
CONDUCTIVITY					
MOLECULAR WEIGHT		18.0		21.2	

ENGINEERING DATA

CORROSION			
SUGGESTED MATERIAL OF CONSTRUCTION			
SOLIDS DEPOSITION LIKELY			
MAX PRESSURE ATA		4.3	
LIMITED BY			
MIN FLUID TEMP 4 °C	ASSOCIATED PRESS.		PSIA
INSULATION REQUIRED			
PURPOSE OF INSULATION			
BRANCH CONNECTIONS			
ANY BRANCH CONNECTIONS TO BE PREPARED FOR WELDING			
SUGGESTED TYPE OF HEAT EXCHANGER			

REMARKS

ISSUED TO PROJECT GROUP DATE BY

DATE MAR 77	HEAT EXCHANGER PROCESS DATA SHEET	SNC	PR DSGN 101
REV			

FIRED HEATER FURNACE

SPEC NO. 5

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION AUXILIARY STEAM GENERATOR		EQUIP NO	E-2
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY JP	CHECKED BY	APPROVED BY
	DATE 18/06/82	DATE	DATE

OPERATING DATA

FLUID CIRCULATED WATER

		NORM OPERATG		DESIGN		START UP	
		IN	OUT	IN	OUT	IN	OUT
TOTAL FLUID RATE	KG/HR	2,500	2,500	3,400	3,400		
VAPOUR RATE	KG/HR		2,500		3,400		
LIQUID RATE	KG/HR	2500		3,400			
PRESSURE	ATA	1.1	4.5	1.2	5.0		
TEMPERATURE	°C	15	149	15	155		
MAX. ALLOWABLE PRESSURE DROP.	–						
MAX. INSIDE FILM TEMP.	°						
HEAT ABSORPTION	/HR						
AVERAGE FLUX DENSITY	–						
VELOCITY LIMITATION							
FOULING FACTOR							
STEAM/AIR DECOKING REQUIREMENT							

PHYSICAL DATA

DENSITY	T/M³	1.0	0.0024	1.0	0.0026		
SPECIFIC HEAT	~~KCAL/KG~~ °C	1.0					
LATENT HEAT							
VISCOSITY AT 20 °C	cP	1.0					
CONDUCTIVITY							
MOLECULAR WEIGHT		18	18				

FUEL AND COMBUSTION DATA

TYPE OF FUEL	LOW/MEDIUM CALORIFIC VALUE GAS		
HEATING VALUE (HHV) 3 – 10 MJ/SCM – (LHV)			
FUEL TEMPERATURE & PRESSURE AT BURNER		80°C	1.1 ATA
VISCOSITY AT		°	cP
DENSITY AT		80° C	0.00026 T/M³
FUEL SULPHUR CONTENT		200 ppm	WEIGHT %
LIQUID FUELS: VANADIUM CONTENT			PPM
SODIUM CONTENT			PPM
GAS: MOLECULAR WIEGHT		27.5	
COMPOSITION H_2 – 12÷17 ; CO – 12÷17 ; CO_2 – 8÷10 ; CH_4 – 0.5÷1.5 ; N_2 – 1÷48			MOLE %
FLUE GAS TEMPERATURE LEAVING SECTION		970	°C
AMBIENT AIR TEMPERATURE		20	°C
ALTITUDE ABOVE SEA LEVEL			

ENGINEERING DATA

CORROSION/EROSION	
SUGGESTED MATERIAL OF CONSTRUCTION	
SOLID DEPOSITION LIKELY	
INSULATION REQUIRED	
LIKELY LIMITATIONS: FLOT	
STACK	
TUBE	
FLAME FAILURE / OTHER PROTECTION / CONTROL REQUIREMENTS:	
SUGGESTED TYPE OF FIRED HEATER FURNACE	
OPERATING (HR/DAY)	24

REMARKS

ISSUED TO PROJECT GROUP DATE BY

DATE MAR 77	FIRED HEATER FURNACE PROCESS DATA SHEET	snc	PR DSGN 112
REV			

PUMP			SPEC NO. 6
GENERAL	PROJECT NO. 6521	PLANT SPOUTED BED ~~GASIFIER~~	SECTION
	FUNCTION TOTAL WATER PUMP		EQUIP. NO. P-1
	FLOWSHEET NO.		DESIGN BOOK NO.
	CALC NO.	PREPARED BY J.P.	CHECKED BY / APPROVED BY
		DATE 12/06/82	DATE / DATE

OPERATING DATA	TYPE		
	SERVICE		
	LIQUID		WATER
	TOTAL FLOW RATE	KG/HR	500 / 4,000
	PUMPING TEMPERATURE	°C	15
	DISCHARGE PRESSURE	ATA	2.0
	SUCTION PRESSURE	ATA	1.0
	DIFFERENTIAL PRESSURE	AT	1.0
	NPSH AVAILABLE ABOVE END		
	NPSH REQUIRED ABOVE END		
	SOLID PERCENT BY WEIGHT		
	TYPE OF SOLID		
	SOLID PARTICLE SIZE		
	PH		
PHYSICAL DATA			
	DENSITY	T/3CM	1.0
	SPECIFIC HEAT	KCAL/KG x °C	1.0
	VISCOSITY	CP	1.0
	VAPOUR PRESSURE AT 20°C	ATA	0.02
	MOLECULAR WEIGHT		18.0

ENGINEERING DATA	CORROSION / EROSION		
	SUGGESTED MATERIAL OF CONSTRUCTION		
	SOLID DEPOSITION LIKELY		
	MAXIMUM PRESSURE	LIMITED BY	
	MINIMUM FLUID TEMPERATURE	1 °C ASSOCIATED PRESSURE	
	INSULATION REQUIRED		
	ESTIMATED BHP OPERATING		HP
	SAFETY PROVISIONS REQUIRED		
	SPECIAL CONSIDERATIONS		
	SUGGESTED TYPE OF PUMP		
	OPERATING (HR/DAY)	24	
UTILITIES	COOLING WATER TEMPERATURE AVAILABLE		°
	HEATING STEAM TEMPERATURE & PRESSURE AVAILABLE	°	
	CURRENT AVAILABLE		
	VOLTAGE		
	PHASE	FREQUENCY	CYCLE

REMARKS	ISSUED TO PROJECT GROUP	DATE / BY

DATE MAR 77	PUMP	SNC	PR DSGN 119
REV.	PROCESS DATA SHEET		

PUMP			SPEC NO.	7
GENERAL	PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER		SECTION
	FUNCTION HEAT EXCHANGER WATER PUMP			EQUIP. NO. P-2
	FLOWSHEET NO.		DESIGN BOOK NO.	
	CALC NO.	PREPARED BY J. P	CHECKED BY	APPROVED BY
		DATE 18/06/82	DATE	DATE

OPERATING DATA	TYPE		
	SERVICE		
	LIQUID		WATER
	TOTAL FLOW RATE	KG/HR	100 1600
	PUMPING TEMPERATURE	°C	15
	DISCHARGE PRESSURE	ATA	2.0
	SUCTION PRESSURE	ATA	1.0
	DIFFERENTIAL PRESSURE	AT	1.0
	NPSH AVAILABLE ABOVE END		
	NPSH REQUIRED ABOVE END		
	SOLID PERCENT BY WEIGHT		
	TYPE OF SOLID		
	SOLID PARTICLE SIZE		
	PH		
PHYSICAL DATA	DENSITY	T/M^3	1.0
	SPECIFIC HEAT	KCAL/KG x °C	1.0
	VISCOSITY	cp	1.0
	VAPOUR PRESSURE AT 20 °C	ATA	0.02
	MOLECULAR WEIGHT		18.0

ENGINEERING DATA	CORROSION / EROSION		
	SUGGESTED MATERIAL OF CONSTRUCTION		
	SOLID DEPOSITION LIKELY		
	MAXIMUM PRESSURE	LIMITED BY	
	MINIMUM FLUID TEMPERATURE	1 °C ASSOCIATED PRESSURE	
	INSULATION REQUIRED		
	ESTIMATED BHP OPERATING		HP
	SAFETY PROVISIONS REQUIRED		
	SPECIAL CONSIDERATIONS		
	SUGGESTED TYPE OF PUMP		
	OPERATING (HR/DAY)	24	
UTILITIES	COOLING WATER TEMPERATURE AVAILABLE		°
	HEATING STEAM TEMPERATURE & PRESSURE AVAILABLE	°	
	CURRENT AVAILABLE		
	VOLTAGE		
	PHASE	FREQUENCY	CYCLE

REMARKS	ISSUED TO PROJECT GROUP	DATE	BY

DATE MAR 77	PUMP	SNC	PR DSGN 119
REV.	PROCESS DATA SHEET		

F

PUMP			SPEC NO. 8	
GENERAL	PROJECT NO. 6521	PLANT SPOUTED BED ~~GASIFIER~~		SECTION
	FUNCTION STEAM GENERATOR WATER PUMP			EQUIP. NO. P-3
	FLOWSHEET NO.		DESIGN BOOK NO.	
	CALC NO.	PREPARED BY IP	CHECKED BY	APPROVED BY
		DATE 17/05/82	DATE	DATE

OPERATING DATA	TYPE		
	SERVICE		
	LIQUID		WATER
	TOTAL FLOW RATE	kg/hr	13400
	PUMPING TEMPERATURE	°C	15
	DISCHARGE PRESSURE	ATA	2.0
	SUCTION PRESSURE	ATA	1.0
	DIFFERENTIAL PRESSURE	AT	1.0
	NPSH AVAILABLE ABOVE END		
	NPSH REQUIRED ABOVE END		
	SOLID PERCENT BY WEIGHT		
	TYPE OF SOLID		
	SOLID PARTICLE SIZE		
	PH		
PHYSICAL DATA	DENSITY	t/m³	1.0
	SPECIFIC HEAT	kcal/kg x °C	1.0
	VISCOSITY	cP	1.0
	VAPOUR PRESSURE AT 20°C	ATA	0.02
	MOLECULAR WEIGHT		18.0

ENGINEERING DATA	CORROSION / EROSION		
	SUGGESTED MATERIAL OF CONSTRUCTION		
	SOLID DEPOSITION LIKELY		
	MAXIMUM PRESSURE	LIMITED BY	
	MINIMUM FLUID TEMPERATURE	° ASSOCIATED PRESSURE	
	INSULATION REQUIRED		
	ESTIMATED BHP OPERATING		HP
	SAFETY PROVISIONS REQUIRED		
	SPECIAL CONSIDERATIONS		
	SUGGESTED TYPE OF PUMP		
	OPERATING (HR/DAY)		
UTILITIES	COOLING WATER TEMPERATURE AVAILABLE		°
	HEATING STEAM TEMPERATURE & PRESSURE AVAILABLE	°	
	CURRENT AVAILABLE		
	VOLTAGE		
	PHASE	FREQUENCY	CYCLE

REMARKS	ISSUED TO PROJECT GROUP	DATE	BY

DATE MAR 77	PUMP PROCESS DATA SHEET	SNC	PR DSGN 119
REV.			

FAN				SPEC NO. 9	
GENERAL	PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER		SECTION	
	FUNCTION AIR BLOWER				EQUIP. NO. B-1
	FLOWSHEET NO.			DESIGN BOOK NO.	
	CALC NO.	PREPARED BY JP		CHECKED BY	APPROVED BY
		DATE 27/04/82		DATE	DATE

			IN	OUT
OPERATING DATA	CIRCULATED GAS		AIR	AIR
	TOTAL GAS RATE	M^3/MIN		18
	TEMPERATURE	°C	20	
	STATIC PRESSURE	ATA		1.5
	PRESSURE DROP	AT		
PHYSICAL DATA	DENSITY	T/M3		0,0018
	SPECIFIC HEAT			
	VISCOSITY	cP		
	MOLECULAR WEIGHT		29	29

ENGINEERING DATA

CORROSION/EROSION

SUGGESTED MATERIAL OF CONSTRUCTION

SAFETY PROVISIONS REQUIRED

SPECIAL CONSIDERATIONS: AIR FILTER

SUGGESTED TYPE OF FAN

OPERATING (HR/DAY)

REMARKS

ISSUED TO PROJECT GROUP DATE BY

DATE MAR 77	FAN PROCESS DATA SHEET	SNC	PR DSGN 110
REV			

FAN			SPEC NO.	10
GENERAL	PROJECT NO.	PLANT SPOUTED BED GASIFIER		SECTION
	FUNCTION	PRODUCT GAS FAN		EQUIP. NO. B-2
	FLOWSHEET NO.		DESIGN BOOK NO.	
	CALC NO.	PREPARED BY IP	CHECKED BY	APPROVED BY
		DATE 27/05/82	DATE	DATE

OPERATING DATA		IN	OUT
	CIRCULATED GAS	LOW/MEDIUM CALORIC GAS	LOW/MEDIUM CALORIC GAS
	TOTAL GAS RATE m^3/min	35 – 600	
	TEMPERATURE °C	80	
	STATIC PRESSURE ata	1.0	
	PRESSURE DROP		
PHYSICAL DATA	DENSITY t/m^3	0.00073	
	SPECIFIC HEAT		
	VISCOSITY cP		
	MOLECULAR WEIGHT	21.2	21.2

ENGINEERING DATA

CORROSION/EROSION

SUGGESTED MATERIAL OF CONSTRUCTION

SAFETY PROVISIONS REQUIRED

SPECIAL CONSIDERATIONS:

SUGGESTED TYPE OF FAN

OPERATING (HR/DAY)

REMARKS

ISSUED TO PROJECT GROUP DATE BY

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REV			

FIRED HEATER FURNACE

SPEC NO. 11

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION START-UP HEATER		EQUIP NO	H-1
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY IP	CHECKED BY	APPROVED BY
	DATE 27/04/82	DATE	DATE

OPERATING DATA

FLUID CIRCULATED		NORM OPERATG		DESIGN		START UP	
		IN	OUT	IN	OUT	IN	OUT
TOTAL FLUID RATE	AIR + PROPANE M³/HR	1254					
VAPOUR RATE	PROPANE M³/HR	36					
LIQUID RATE	KG/HR	97.2					
PRESSURE	ATA		1.5				
TEMPERATURE	°C	20					
MAX. ALLOWABLE PRESSURE DROP.	AT						
MAX. INSIDE FILM TEMP.	°C						
HEAT ABSORPTION	MJ/HR						
AVERAGE FLUX DENSITY							
VELOCITY LIMITATION							
FOULING FACTOR							
STEAM/AIR DECOKING REQUIREMENT							

PHYSICAL DATA

DENSITY							
SPECIFIC HEAT							
LATENT HEAT							
VISCOSITY AT °F	cP						
CONDUCTIVITY							
MOLECULAR WEIGHT							

FUEL AND COMBUSTION DATA

TYPE OF FUEL	PROPANE			
HEATING VALUE (HHV)	46.45 MJ/KG (LHV)			
FUEL TEMPERATURE & PRESSURE AT BURNER		20°C	1.5 ATA	
VISCOSITY AT /		•	cP	
DENSITY AT		20°C	0.0027 T/M³	
FUEL SULPHUR CONTENT	NONE			WEIGHT %
LIQUID FUELS: VANADIUM CONTENT				PPM
SODIUM CONTENT				PPM
GAS: MOLECULAR WIEGHT	44.1			
COMPOSITION	PROPANE	100		MOLE %
FLUE GAS TEMPERATURE LEAVING SECTION	910			°C
AMBIENT AIR TEMPERATURE	20			°C
ALTITUDE ABOVE SEA LEVEL				

ENGINEERING DATA

CORROSION/EROSION	
SUGGESTED MATERIAL OF CONSTRUCTION	
SOLID DEPOSITION LIKELY	
INSULATION REQUIRED	
LIKELY LIMITATIONS: PLOT	
STACK	
TUBE	
FLAME FAILURE / OTHER PROTECTION / CONTROL REQUIREMENTS:	
SUGGESTED TYPE OF FIRED HEATER FURNACE	
OPERATING (HR/DAY)	

REMARKS

ISSUED TO PROJECT GROUP	DATE	BY

DATE MAR 77	FIRED HEATER FURNACE PROCESS DATA SHEET	SNC	PR DSGN 112
REV			

FIRED HEATER FURNACE

SPEC NO. 12

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION INCINERATOR		EQUIP NO	H-2
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY IP	CHECKED BY	APPROVED BY
	DATE 18/05/82	DATE	DATE

OPERATING DATA

FLUID CIRCULATED		NORM OPERATG		DESIGN		START UP	
		IN	OUT	IN	OUT	IN	OUT
TOTAL FLUID RATE	M3/HR		35,000		50,000		
VAPOUR RATE	M3/HR	1930		2,500			
LIQUID RATE	/HR						
PRESSURE	ATA	1.1		1.7			
TEMPERATURE	°C	80	970	1000			
MAX. ALLOWABLE PRESSURE DROP.							
MAX. INSIDE FILM TEMP.							
HEAT ABSORPTION	/HR						
AVERAGE FLUX DENSITY							
VELOCITY LIMITATION							
FOULING FACTOR							
STEAM/AIR DECOKING REQUIREMENT							

PHYSICAL DATA

DENSITY							
SPECIFIC HEAT							
LATENT HEAT							
VISCOSITY AT °F	cp						
CONDUCTIVITY							
MOLECULAR WEIGHT							

FUEL AND COMBUSTION DATA

TYPE OF FUEL	LOW / MEDIUM CALORIFIC VALUE GASES		
HEATING VALUE (HHV)	3-10 MJ/SCM (LHV)		
FUEL TEMPERATURE & PRESSURE AT BURNER		80°C	1.1 ATA
VISCOSITY AT		°	cp
DENSITY AT		80°C	0.00026 T/M³
FUEL SULPHUR CONTENT		200 ppm	WEIGHT %
LIQUID FUELS: VANADIUM CONTENT			PPM
SODIUM CONTENT			PPM
GAS: MOLECULAR WIEGHT		27.5	
COMPOSITION	H_2-12÷17; CO-12÷17; CO_2-8÷10; CH_4-0.5÷1.5; N_2-1÷48		MOLE %
FLUE GAS TEMPERATURE LEAVING SECTION		970	°C
AMBIENT AIR TEMPERATURE		20	°C
ALTITUDE ABOVE SEA LEVEL			

ENGINEERING DATA

CORROSION/EROSION	
SUGGESTED MATERIAL OF CONSTRUCTION	
SOLID DEPOSITION LIKELY	
INSULATION REQUIRED	
LIKELY LIMITATIONS: PLOT	
STACK	
TUBE	
FLAME FAILURE / OTHER PROTECTION / CONTROL REQUIREMENTS:	
SUGGESTED TYPE OF FIRED HEATER FURNACE	
OPERATING (HR/DAY)	

REMARKS

ISSUED TO PROJECT GROUP	DATE	BY

GRINDING

SPEC NO. 13

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION COAL CRUSHER		EQUIP. NO. CR-1	
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY JP	CHECKED BY	APPROVED BY
	DATE 27/04/82	DATE	DATE

PARTICLE PROPERTIES

MATERIAL COAL

HARDNESS STRUCTURE

		MATERIAL IN	MATERIAL OUT
PARTICLE SIZE	SQ/	2 to 1	-6.35
DISTRIBUTION	%		90
BASIS			
METHOD			
LIMITING PARTICLE SIZE			-6.35 +1.00
TEMPERATURE	°C	20	
MOISTURE	%	20	
SPECIFIC HEAT			
THERMAL CONDUCTIVITY			
DENSITY	T/M³	1.43	
BULK DENSITY	T/M³	0.74	
AIR PERMEABILITY			
AVERAGE PARTICLE SIZE			3.36
WEIGHT AVERAGE SIZE			
SURFACE SHAPE FACTOR		0.70	
VOLUME SHAPE FACTOR			
SPECIFIC SURFACE FACTOR			
SPECIFIC SURFACE			

LABORATORY GRINDING TESTS

GRINDABILITY 34 ÷ 92 NET WORK

EFFICIENCY CONSTANTS

ABRASIVENESS

TEST DETAILS

STABILITY/EXPLOSION HAZARD/HEAT SENSITIVITY

STICKINESS/FLOWABILITY

GRINDING RATE 5,000 KG/HR EST POWER REQUIRED KW WET ☐ /DRY ☐ GRINDING

MATERIAL TEMPERATURE IN 20 °C ON GRINDING °F OUT °F

GRINDING AID TYPE QUANTITY

REMARKS

ISSUED TO PROJECT GROUP DATE BY

DATE MAY 77	GRINDING PROCESS DATA SHEET	snc	PR DSGN 125 PAGE 1 of 2
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GRINDING — SPEC NO. 13

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION COAL CRUSHER		EQUIP. NO. CR-1	
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY JP	CHECKED BY	APPROVED BY
	DATE 27/04/82	DATE	DATE

TYPE OF GRINDING — BATCH ☐ · CONTINUOUS OPEN CIRCUIT ☒ · CONTINUOUS CLOSED CIRCUIT ☐

CIRCUIT LOAD % PRODUCTION

CLASSIFICATION METHOD SCREENING

	GRINDING ATMOSPHERE		NET GRINDING	HEATING/COOLING
PHASE	IN	OUT	LIQUID	MEDIUM
DESCRIPTION	AIR	AIR		
FLOWRATE KG/HR				
ANALYSIS				
SPECIFIC HEAT —				
VISCOSITY cP				
THERMAL COND.				
DENSITY				
TEMPERATURE in-out °F				
HUMIDITY/MOISTURE				
DUST LOADING				
DUST SIZE DISTRIBUTION				
BASIS				
METHOD				

MATERIAL OF CONSTRUCTION

SAFETY PROVISIONS

OTHER FEATURES

OPERATING TIME 6 HRS/DAY

OPERATING CYCLE 6 HRS

RECOMMENDED EQUIPMENT TYPE

POSSIBLE MANUFACTURERS

REMARKS

ISSUED TO PROJECT GROUP — DATE — BY

SCREENS

SPEC NO. 14

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION SCREEN		EQUIP. NO. SC-1	
FLOWSHEET NO.	DESIGN BOOK NO.		
CALC NO.	PREPARED BY JP	CHECKED BY	APPROVED BY
	DATE 23/04/82	DATE	DATE

SEPARATION(S) REQUIRED

LOCATION / CONTEXT

OPERATING	6 HRS/DAY	FEED	U/SIZE	RETAINED	O/SIZE	OPEN CIRCUIT	☐
MATERIAL		COAL				CLOSED CIRCUIT	☐
AVE/MAX RATE	KG/HR	5,000				OPEN SCREENS	☐
TEMPERATURE	°C	20				ENCLOSED SCREENS	☐
ASSAY						LIMITED SPACE	☐
						SIEVE HOLE REQ'D	
						SQUARE	☐
MOISTURE	%	20				SLOTS	☐
PARTICLE SIZE	mm			-6.35 + 1.00		RECTANGULAR	☐
DISTRIBUTION						ANY	☐
BASIS:						OTHER	
						DRY SCREENING	☐
METHOD:						WET SCREENING	☐
						WETTING LIQUID	
LIMITING PARTICLE SIZE						AVE RATE	
DENSITY	T/M³	1.43				MAX RATE	
BULK DENSITY	T/M³	0.74				TEMPERATURE	°
PARTICLE SHAPE							
ANGLE OF REPOSE							
FLOWABILITY							
HARDNESS							

CORROSION / ABRASION

TESTS

LAB SCREENING TESTS

STABILITY/HT. SENSITIVITY/EXPLOSION RISK

SAFETY/OTHER FACTORS

RECOMENDED TYPE

MANUFACTURERS

REMARKS

ISSUED TO PROJECT GROUP DATE BY

PRESSURE VESSEL / TANK DATA

SPEC NO. 15

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER		SECTION
FUNCTION COAL FEEDER			EQUIP. NO. FE-1
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY IP	CHECKED BY	APPROVED BY
	DATE 27/04/82	DATE	DATE

OPERATING DATA

SPECIFIC CAPACITY		M^3
VOLUME OF FLUID	13.5	M^3
WEIGHT OF FLUID	10	T
AGITATION		
SUGGESTED DIMENSIONS		
OPERATING TEMPERATURE	20	°C
OPERATING PRESSURE	1.0	ATA
MAXIMUM FLUID TEMPERATURE		°C
HEATING / COOLING BY	USING	AT AND °C
FLASH POINT OF CONTENTS		

PHYSICAL DATA

DENSITY (BULK)	0.74	T/M3
SPECIFIC HEAT		
VISCOSITY		cP

ENGINEERING DATA

CORROSION	
SUGGESTED MATERIAL OF CONSTRUCTION	
SOLIDS DEPOSITION LIKELY	
MAXIMUM PRESSURE	LIMITED BY
MINIMUM FLUID TEMPERATURE °	ASSOCIATED PRESSURE
INTERNAL FITTINGS	
EXTERNAL FITTINGS	
INSULATION REQUIRED	
PURPOSE OF INSULATION	
ACCESS REQUIRED	
BRANCH CONNECTIONS	
ANY BRANCH CONNECTIONS TO BE PREPARED FOR WELDING	
SUGGESTED TYPE OF PRESSURE VESSEL/TANK	
OPERATING (HR/DAY)	

REMARKS

ISSUED TO PROJECT GROUP	DATE	BY

DATE MAR 77 REV	PRESSURE VESSEL / TANK PROCESS DATA SHEET	SNC	PR DSGN 118

CONVEYOR				SPEC NO. 16
GENERAL	PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER		SECTION
	FUNCTION SCREW CONVEYER			EQUIP. NO. CO-1
	FLOWSHEET NO.		DESIGN BOOK NO.	
	CALC NO.	PREPARED BY JP	CHECKED BY	APPROVED BY
		DATE 27/04/82	DATE	DATE

OPERATING DATA			IN	OUT
LOADING CONTINUOUS/INTERMITENT			CONT.	
MATERIAL CONVEYED			COAL	COAL
TOTAL RATE		TONS/HR		
AVERAGE		TONS/HR	0.500	
PEAK		TONS/HR	0.700	
MOISTURE		WEIGHT %	20	
TEMPERATURE		°C	20	
MAXIMUM TEMPERATURE		°C	40	
PRESSURE		ATA	1.0	
PNEUMATIC CONVEYORS				YES
CONVEYING FLUID				AIR
REQUIRED RATE (AV/MAX)			1	1
MIN/MAX INLET TEMPERATURE		°C	1	

MATERIAL DATA					
BULK DENSITY	POURED		TAPPED		
	STORED	0.74	AERATED		T/M³
ANGLE OF REPOSE					deg.
PARTICULE SHAPE & SIZE					
SPECIAL CHARACTERISTICS					
FLOWABILITY					
ABRASIVENESS					
FLAMABILITY	YES				

ENGINEERING DATA	
CORROSION	
SUGGESTED MATERIAL OF CONSTRUCTION	
INSTALLATION	INSIDE/OUTSIDE
INSULATION	
PURPOSE OF INSULATION:	
SAFETY PROVISIONS REQUIRED	
SPECIAL CONSIDERATIONS	
SUGGESTED CONVEYOR TYPE	
OPERATING (HR/DAY)	

REMARKS		
ISSUED TO PROJECT GROUP	DATE	BY

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PRESSURE VESSEL / TANK DATA

SPEC NO. 17

GENERAL

PROJECT NO. 6521	PLANT		SECTION
FUNCTION CHAR RECEIVER			EQUIP. NO. RE-1
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY IP	CHECKED BY	APPROVED BY
	DATE 27/04/82	DATE	DATE

OPERATING DATA

SPECIFIC CAPACITY	0.25	M^3
VOLUME OF FLUID	0.073	M^3
WEIGHT OF FLUID	54	KG/HR
AGITATION		
SUGGESTED DIMENSIONS		
OPERATING TEMPERATURE	950	°C
OPERATING PRESSURE	1.0	ATA
MAXIMUM FLUID TEMPERATURE	1150	°C
HEATING / COOLING BY	USING AT	AND °
FLASH POINT OF CONTENTS		

PHYSICAL DATA

DENSITY (BULK)	0.74	
SPECIFIC HEAT		
VISCOSITY		cP

ENGINEERING DATA

CORROSION	
SUGGESTED MATERIAL OF CONSTRUCTION	
SOLIDS DEPOSITION LIKELY	
MAXIMUM PRESSURE	LIMITED BY
MINIMUM FLUID TEMPERATURE °	ASSOCIATED PRESSURE
INTERNAL FITTINGS	
EXTERNAL FITTINGS	
INSULATION REQUIRED	
PURPOSE OF INSULATION	
ACCESS REQUIRED	
BRANCH CONNECTIONS	
ANY BRANCH CONNECTIONS TO BE PREPARED FOR WELDING	
SUGGESTED TYPE OF PRESSURE VESSEL/TANK	
OPERATING (HR/DAY)	

REMARKS

ISSUED TO PROJECT GROUP	DATE	BY

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CYCLONES

SPEC NO. 18

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER		SECTION
FUNCTION CYCLONE			EQUIP. NO. CY-1
FLOWSHEET NO.		DESIGN BOOK NO.	
CALC NO.	PREPARED BY JP	CHECKED BY	APPROVED BY
	DATE 17/05/82	DATE	DATE

INPUT PRESSURE NORMAL 1.1 ATA MAXIMUM 1.5 ATA

PERMITTED PRESSURE DROP 0.02 AT

COLLECTION EFFICIENCY 70 % BY WEIGHT

	SUSPENDED MATERIAL			SUSPENSION MEDIUM		
	IN	REMOVED	OUT	IN	REMOVED	OUT
PHASE DESCRIPTION	SOLID	SOLID	SOLID	GAS		GAS
FLOWRATE KG/HR	107	75	32	2176		2176
COMPOSITION						
SIZE / WEIGHT % REMOVED						
PARTICLE 2-0.1 mm / 99	UNBURNED COAL + DUST	UNBURNED COAL	DUST			
SIZE DISTRIBUTION			100-0.1 μ			
WEIGHT %						
METHOD						
MOISTURE/HUMIDITY				5.2%		
DENSITY t/m³	1.43			0.00022		
BULK DENSITY t/m³	0.74					
TEMPERATURE °C				940		
DEW POINT °C				41		
VISCOSITY cP						
SPECIFIC HEAT kcal/kg x °C				0.33		
THERMAL CONDUCTIVITY						
DUST LOADING						
STRUCTURE						
HARDNESS						
TENDENCY TO AGGLOMERATE						
STICKINESS/FLOWABILITY						
ABRASIVENESS/CORROSION						
TEST						
STABILITY/EXPLOSION						
HAZARD/HEAT SENSITIVITY						

REMARKS

ISSUED TO PROJECT GROUP DATE BY

CYCLONES			SPEC NO. 18
GENERAL	PROJECT NO. 6521	PLANT SPOUTED BED ~~GA~~SIFIER	SECTION
	FUNCTION CYCLONE		EQUIP. NO. CY-1
	FLOWSHEET NO.		DESIGN BOOK NO.
	CALC NO.	PREPARED BY JP	CHECKED BY / APPROVED BY
		DATE 17/05/82	DATE / DATE

INSULATION REQUIRED	YES
MATERIAL OF CONSTRUCTION	
SAFETY PROVISIONS	
OTHER FEATURES	
OPERATION	HRS/DAY
NORMAL CYCLE TIME	
RECOMMENDED EQUIPMENT TYPE	
POSSIBLE MANUFACTURERS	

REMARKS	ISSUED TO PROJECT GROUP	DATE	BY

CYCLONES

SPEC NO. 19

GENERAL

PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION	
FUNCTION CYCLONE		EQUIP. NO. CY-2	
FLOWSHEET NO.	DESIGN BOOK NO.		
CALC NO.	PREPARED BY JP	CHECKED BY	APPROVED BY
	DATE 17/05/82	DATE	DATE

INPUT PRESSURE NORMAL 1.1 ATA MAXIMUM 1.5 ATA

PERMITTED PRESSURE DROP 0.02AT

COLLECTION EFFICIENCY 80 % BY WEIGHT

	SUSPENDED MATERIAL			SUSPENSION MEDIUM		
	IN	REMOVED	OUT	IN	REMOVED	OUT
PHASE DESCRIPTION	SOLID	SOLID	SOLID	~~GAS~~		~~GAS~~
FLOWRATE ~~LB~~ KG/HR	32	26	6	2176		2176
COMPOSITION						
SIZE (μ) / WEIGHT % REMOVED	DUST	DUST	DUST			
PARTICLE SIZE (100-5 μ, 95)			5-0.1			
DISTRIBUTION						
WEIGHT %						
METHOD						
MOISTURE/HUMIDITY				5.2%		
DENSITY t/m³	1.43			0.00022		
BULK DENSITY t/m³	0.74					
TEMPERATURE °C				930		
DEW POINT °C				41		
VISCOSITY cP						
SPECIFIC HEAT kcal/kg x °C				0.33		
THERMAL CONDUCTIVITY						
DUST LOADING						
STRUCTURE						
HARDNESS						
TENDENCY TO AGGLOMERATE						
STICKINESS/FLOWABILITY						
ABRASIVENESS/CORROSION						
TEST						
STABILITY/EXPLOSION						
HAZARD/HEAT SENSITIVITY						

REMARKS

ISSUED TO PROJECT GROUP DATE BY

DATE MAY 77	CYCLONES PROCESS DATA SHEET	SNC	PR DSGN 122 PAGE 1 of 2
REV			

CYCLONES			SPEC NO. 19
GENERAL	PROJECT NO. 6521	PLANT SPOUTED BED GASIFIER	SECTION
	FUNCTION CYCLONE		EQUIP. NO. CY-2
	FLOWSHEET NO.		DESIGN BOOK NO.
	CALC NO.	PREPARED BY JP	CHECKED BY / APPROVED BY
		DATE 17/05/82	DATE / DATE

INSULATION REQUIRED	YES
MATERIAL OF CONSTRUCTION	
SAFETY PROVISIONS	
OTHER FEATURES	
OPERATION	HRS/DAY
NORMAL CYCLE TIME	
RECOMMENDED EQUIPMENT TYPE	
POSSIBLE MANUFACTURERS	

REMARKS	ISSUED TO PROJECT GROUP	DATE	BY

LOWELL — FORM A-610 (D)
PROCÉDÉ *Plasdex*® PROCESS
MONTRÉAL, QUÉBEC

APPENDIX F

BASIS OF ESTIMATE

APPENDIX F

BASIS OF ESTIMATE

This is a preliminary cost estimate for the 12 tonnes dry coal per day Process Development Unit Spouted Bed Coal Gasifier facility.

The estimate includes the sitework, the building cost including the foundations, structural steel, mechanical and electrical services, the process equipment and associated civil, electrical and automation works. No provision has been made for items identified "rented". The cost of these items is included in operating costs.

The estimate is based on the following drawings:

- P & I Diagram (Drawing number 6521-49DD-001 Rev. PC).
- General Arrangement Drawing number 6521-49DD-002 Rev. PB.

Costs shown under the "Labor" columns are subcontractor rates including wages, burdens, fringe benefits, field supervision, temporary facilities, small tools, equipment rental, home office cost, and profit. The hourly labor rate has been fixed at $40.00 for Vancouver, B.C., and is based on 40-hours week.

Cost shown under the "Material" columns include cost of material F.O.B. Vancouver, British Columbia, and profit.

Costs shown under the "Permanent Equipment" column include cost of major equipment F.O.B. Vancouver, British Columbia. Equipment prices were obtained from written quotations and budget telephone quotations.

Costs shown under the "Subcontractor" column include all labor, material, subcontractor indirect cost, overhead and profit.

The validity base date of this estimate is May, 1983. It reflects all wage rates, material and equipment price as of May, 1983.

An overall contingency of 15% has been included. This contengency provides allowance for elements of costs within the defined scope of this estimate that cannot be explicitly foreseen or described, at the time the estimate was made, because of the lack of complete, accurate, and detailed information. It specifically excludes any change order or change of scope.

The accuracy of this preliminary estimate is $\pm$ 20%.

snc

LOVELL - FORM A-8(11)
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MONTRÉAL, QUÉBEC

APPENDIX G

DETAILED ESTIMATE

COST ESTIMATE SUMMARY

DIVISION

CLIENT: DEPT. OF ENERGY, MINES & RESOURCES - CANMET

PROJECT: SPOUTED BED GASIFIER

LOCATION

DESCRIPTION: CAPITAL COST SUMMARY

CURRENCY RATE

BY R. DUVAL DATE 82-05-03 EST. NO

SHEET OF

CONTR. 6521 SUBD. 0000

ITEM	U	QTY	MANHRS TOTAL	LABOUR COST	MATERIAL COST	PERM. EQUIP. COST	SUB CONTR. COST	CONST. EQUIP COST	TOTAL U	TOTAL COST
SITE WORK							65585			65600
BUILDING							243000			243000
MECHANICAL EQUIPMENT				118300	12800	53300	120⚠00			665400
MECH. EQUIP. CIVIL WORKS							124000			124000
MECHANICAL PIPING		8%	OF TOTAL EQUIPMENT COST			(65340⚠0)				52200
ELECTRICAL		15%		DITTO						98000
AUTOMATION		14%		DITTO						91500
S/TOTAL										1339700
SNC INC. SERVICES		20%								267940
CONTENGENCY		15%								241146
										1848786

3300 03E/0

SNC

COST ESTIMATE

CLIENT: DEPT. OF ENERGY MINES & RESOURCES

DESCRIPTION: SPOUTED BED GAZIFIER — SITE WORK

BY: R.D. DATE: 82-05-10 EST. NO: PRELIMINARY

SHEET 1 OF

CONTR.	SUBD.	TRADE
6521	0000	

CODE W/E	ITEM	U	QTY	MANHRS U	TOTAL	LABOUR U	COST	MATERIAL U	COST	PERM. EQUIP. U	COST	SUB CONTR. U	COST	CONST. EQUIP. U	COST	TOTAL U	COST
	SITE CLEARING AND GRUBBING.	S.F.	80,000										2000				
	SITE GRADING, FILING AND COMPACTING:	S.F.	80,000														
		C.Y.	5000									3.00/C.Y.	15000				
	ACCESS ROAD	L.F.	250									15.00/L.F.	3750				
	RAILROAD C/W ONE SWITCH, & ONE BUMPER	L.F.	350			SW: -	50.00	BUMPER: 5,000.00				90.00/L.F.	52000				
	TRENCH EXCAVATION FOR SITE DRAINAGE	C.Y.	400									6.00/C.Y.	2400				
	DISPOSAL	C.Y.	400									4.00/C.Y.	1600				
	TRENCH EXCAVATION FOR WATER & SEWER LINES & GAS LINE	C.Y.	65									6.00/C.Y.	420				
	GRANULAR BACKFILL	C.Y.	20									14.00/C.Y.	280				
	COMMON BACKFILL	C.Y.	45									3.00/C.Y.	135				
													65585				65585

3300 - 04E/0

SNC

COST ESTIMATE SUMMARY

CLIENT

PROJECT SPOUTED BED GASIFIER

DIVISION

LOCATION

DESCRIPTION MECHANICAL EQUIPMENT

CURRENCY RATE

BY R.D. DATE 82-05-17 EST. NO

SHEET 2 OF

CONTR. 6521 SUBD. 0000

	ITEM	U	QTY	MANHRS TOTAL	LABOUR COST	MATERIAL COST	PERM. EQUIP. COST	SUB CONTR. COST	CONST. EQUIP COST	TOTAL U	TOTAL COST
	SHEET # 3				12900	2100	54000				69000
	" # 4				20700	1900	108100				130700
	" # 5				13400	1800	115600				130800
	" # 6				37100	4800	210000				251900
	" # 7				34200	2200	34600				71000
					118300	12800	522300				653400

3300 03E/0

SNC

COST ESTIMATE

CLIENT

DESCRIPTION: SPOUTED BED GASIFIER — MECHANICAL EQUIPMENT

BY: R.D. DATE: 82-05-10 EST. NO: PREL.

SHEET 3 OF

CONTR.	SUBD.	TRADE
6521	0000	

CODE W/E	ITEM	U	QTY	MANHRS U	MANHRS TOTAL	LABOUR U	LABOUR COST	MATERIAL U	MATERIAL COST	PERM. EQUIP. U	PERM. EQUIP. COST	SUB CONTR. U	SUB CONTR. COST	CONST. EQUIP. U	CONST. EQUIP. COST	TOTAL U	TOTAL COST
	MECHANICAL EQUIPMENT																
	RAILCAR CLAMSHELL UNLOADER 40T/HR.	EA.	1		N.A.						(RENTED)						
	FRONT END WHEEL UNLOADER 5 C.Y. BUCKET CAT. # 930 OR EQUAL	EA.	1		N.A.						(RENTED)						
	MOBILE STACKER CONV. 80T/HR. 24" x 30'	EA.	1				1000				10000						10100
	FIXED CONVEYOR 24"-65'	EA.	1				7000		1000		20000						28000
	C/W BENT SUPPORTS	T.	17.		(REFER SHEET N° 9)												18500
	HOPPER & GRIZZLY 40T. 15'x15'x 21.3 STEEL	T.	6				3000		500		15000						
	SCREW CONVEYOR 11T/HR 16"ϕ x 12'	EA.	2			150/EA.	1500		500	3500/EA.	7000						9000
	SCREW CONVEYOR 1 TON/HR.	EA.	1				400		100	EA.	2000						2500
							12900		2100		54000						68100

3300 03E/0

SNC COST ESTIMATE

CLIENT

DESCRIPTION: SPOUTED BED GASIFIER — MECHANICAL EQUIPMENT

BY R.D. DATE 82-05-10 EST. NO PEEL.

SHEET 4 OF

CONTR.	SUBD.	TRADE
6521	0000	

CODE W/E	ITEM	U	QTY	MANHRS U	MANHRS TOTAL	LABOUR U	LABOUR COST	MATERIAL U	MATERIAL COST	PERM. EQUIP. U	PERM. EQUIP. COST	SUB CONTR. U	SUB CONTR. COST	CONST. EQUIP. U	CONST. EQUIP. COST	TOTAL U	TOTAL COST
	FIXED EQUIPMENT CON'TD																
	HAMMER MILL CRUSHER 11T/HR. JEFFREY 30WB C/W 50HP. X-PROOF MOTOR, CONT.	EA.	1			20HR T.	3200		400		18000						21600
	& CHUTE WORKS																
	BUCKET ELEVATOR 11T/HR. C/W 10 HP. X-PROOF MOTOR & CONTROLS, JEFFREY	EA.	1				7000		500		30000						37500
	14×8×11 3/4×40'																
	VIBRATING SCREEN, 2'×4" C/W X-PROOF DRIVE	EA.	1				600		100		4600						5300
	VIBRATING SCREEN ENCLOSURE	EA.	1				500		100		2500						3100
	VIB. SCREEN CHUTE WORKS	EA.	1				1000		200		5000						6200
	HOPPER 10TON CAPACITY	T.	3				800		200		10000						11000
	WEIGH FEEDER 1/2-1T/HR. 18"×9" C/W 1/2HP X-PROOF MOTOR & COAL SAMPLER	EA.	1				7600		400		38000						46000
							20700		1900		108100						130700

3300 03E/0

SNC COST ESTIMATE

CLIENT

DESCRIPTION: SPOUTED BED GASIFIER
MECHANICAL EQUIPMENT
BY R.D. DATE 82-05-10 EST. NO PEEL.

SHEET 5 OF

CONTR.	SUBD.	TRADE
6521	0000	

CODE W/E	ITEM	U	QTY	MANHRS U	MANHRS TOTAL	LABOUR U	LABOUR COST	MATERIAL U	MATERIAL COST	PERM. EQUIP. U	PERM. EQUIP. COST	SUB CONTR. U	SUB CONTR. COST	CONST. EQUIP. U	CONST. EQUIP. COST	TOTAL U	TOTAL COST
	FIXED EQUIPMENT CONT'D.																
	STAR FEEDER 1/2-1T/HR. C/W 1HP X-PROOF MOTOR & ADAPTOR	EA.	1				1200		100		8500						9800
	BLOWER ASSEMBLY 300 CFM/6PSIG C/W 25HP X-PROOF MOTOR.	EA.	2			400/80.	3000		300	7850	15700						19000
	BURNER ASSEMBLY AIR/BED PRE-HEATER	EA.	1				2500		500		25000						28000
	BURNER ASSEMBLY PRODUCED GAS INCINERATOR	EA.	1				3500		500		35000						39000
	CHAR SAMPLER	EA.	1				1000		100		5000						6100
	GAS SAMPLER	EA.	1				1200		200		20000						21400
	CYCLONE 2163 Kg/Hr. 900°F REFRACTOR - SS 304	EA.	1				1000		100		6400						7500
							13400		1800		115600						130800

3300 03E/0

SNC COST ESTIMATE

CLIENT

DESCRIPTION: SPOUTED BED GASIFIER — MECHANICAL EQUIPMENT

BY: R.D. DATE: 82.05.10 EST. NO: PEEL.

SHEET 6 OF

CONTR.	SUBD.	TRADE
6521	0000	

CODE W/E	ITEM	U	QTY	MANHRS U	MANHRS TOTAL	LABOUR U COST	MATERIAL U COST	PERM. EQUIP. U COST	SUB CONTR. U COST	CONST. EQUIP. U COST	TOTAL U COST
	GASIFIER REACTOR VESSEL MILD STEEL & REFRACTORY 30' HIGH x 4'6" DIA.	EA.	1			20000	3000	75000			98000
	HEAT EXCHANGER 20" DIA. x 25'-0" UNFIRED STEAM BOILER MUREHEAD MODEL	EA.	1			1800	200	30000			32000
	STEAM DRUM: 3' ϕ x 20'-0 MUREHEAD	EA.	1			1200	200	5000			6400
	FAN 1400 CFM @ 400°F C/W X-PROOF MOTOR & CONTROLS	EA.	1			800	200	7000			8000
	STACK 1400 CFM 36" ϕ x 75' PLATE 1/4" 10.2 Lbs/S.F.	EA.	5500 Lbs			1300	200 2.38/Lb.	13000			14500
	STEAM GENERATOR BOILER 3000 Lbs/HR. 1000 KW EACH.	EA.	2			12000	1000 40K/ea.	80000			93000
						37100	4800	210000			251900

SNC

COST ESTIMATE

CLIENT

DESCRIPTION: SPOUTED BED GASIFIER — MECHANICAL EQUIPMENT

BY R.D. DATE 82-05-10 EST. NO PREL.

SHEET 7 OF

CONTR	SUBD	TRADE
6521	0000	

CODE W/E	ITEM	U	QTY	MANHRS U	MANHRS TOTAL	LABOUR U	LABOUR COST	MATERIAL U	MATERIAL COST	PERM. EQUIP. U	PERM. EQUIP. COST	SUB CONTR. U	SUB CONTR. COST	CONST. EQUIP. U	CONST. EQUIP. COST	TOTAL U	TOTAL COST
	WATER TREATMENT UNIT	EA.	2				1200		200	3000/EA.	5600						7000
	OXYGEN BULK TANK & VAPORIZER									(RENTED)							
	DUST COLLECTOR AND BAGHOUSE (2000 CFM)	EA.	1				5000		1000		7000						13000
	GAS DUCT WORKS 20"ϕ S.S.	L.F.	100'				28000		1000	220/L.F.	22000						51000
	TAR REMOVAL EQSUIP.												120⚠00				120⚠00
							34200		2200		34600		120⚠00				83⚠000

3300 03E/0

SMC COST ESTIMATE

CLIENT

DESCRIPTION: SPOUTED BED GASIFIER

MECH. EQUIP. CIVIL WORKS

BY | DATE | EST. NO

SHEET 8 OF

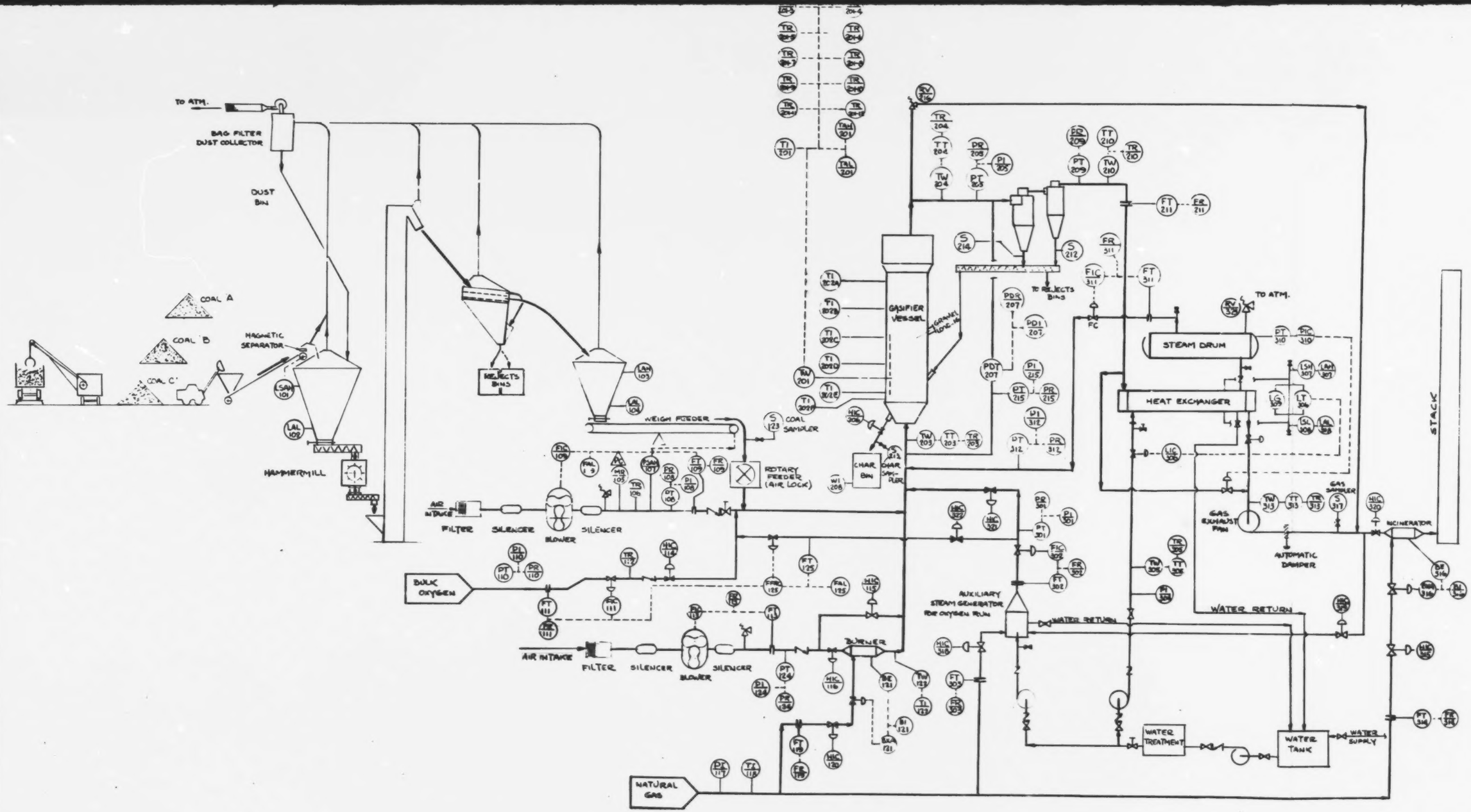
CONTR.	SUBD.	TRADE
6521	0000	

CODE W/E	ITEM	U	QTY	MANHRS U	MANHRS TOTAL	LABOUR U	LABOUR COST	MATERIAL U	MATERIAL COST	PERM. EQUIP. U	PERM. EQUIP. COST	SUB CONTR. U	SUB CONTR. COST	CONST. EQUIP. U	CONST. EQUIP. COST	TOTAL U	TOTAL COST
	FOUNDATION																
	6% OF MECH. EQUP. (662,000)												40000				
	STELL STRUCTURE																
	SUPPORT FOR HAMMER MILL & HOPPER ASSBL'Y	T	13									2150	28000				
	SUPPORT FOR BUCKET ELEVATOR, VIB. SCREEN & WEIGHFEEDER ASSEMBLY	T	6									2150	13000				
	SUPPORT FOR GASIFIER, CYCLONE, STEAM DRUM & EXCHANGER ASSEMBLY	T	20									2150	43000				
													124000				124000

LOVELL - FORM A-610(B)
PROCÉDÉ Plandex® PROCESS
MONTRÉAL, QUÉBEC

APPENDIX H

PROCESS AND EQUIPMENT DRAWINGS



ISSUE	REV	DATE	STATUS & DISTRIBUTION	ISSUE	REV	DATE	STATUS & DISTRIBUTION

RECORD OF DRAWING ISSUE

No	REFERENCE DRAWINGS	No	REFERENCE DRAWINGS

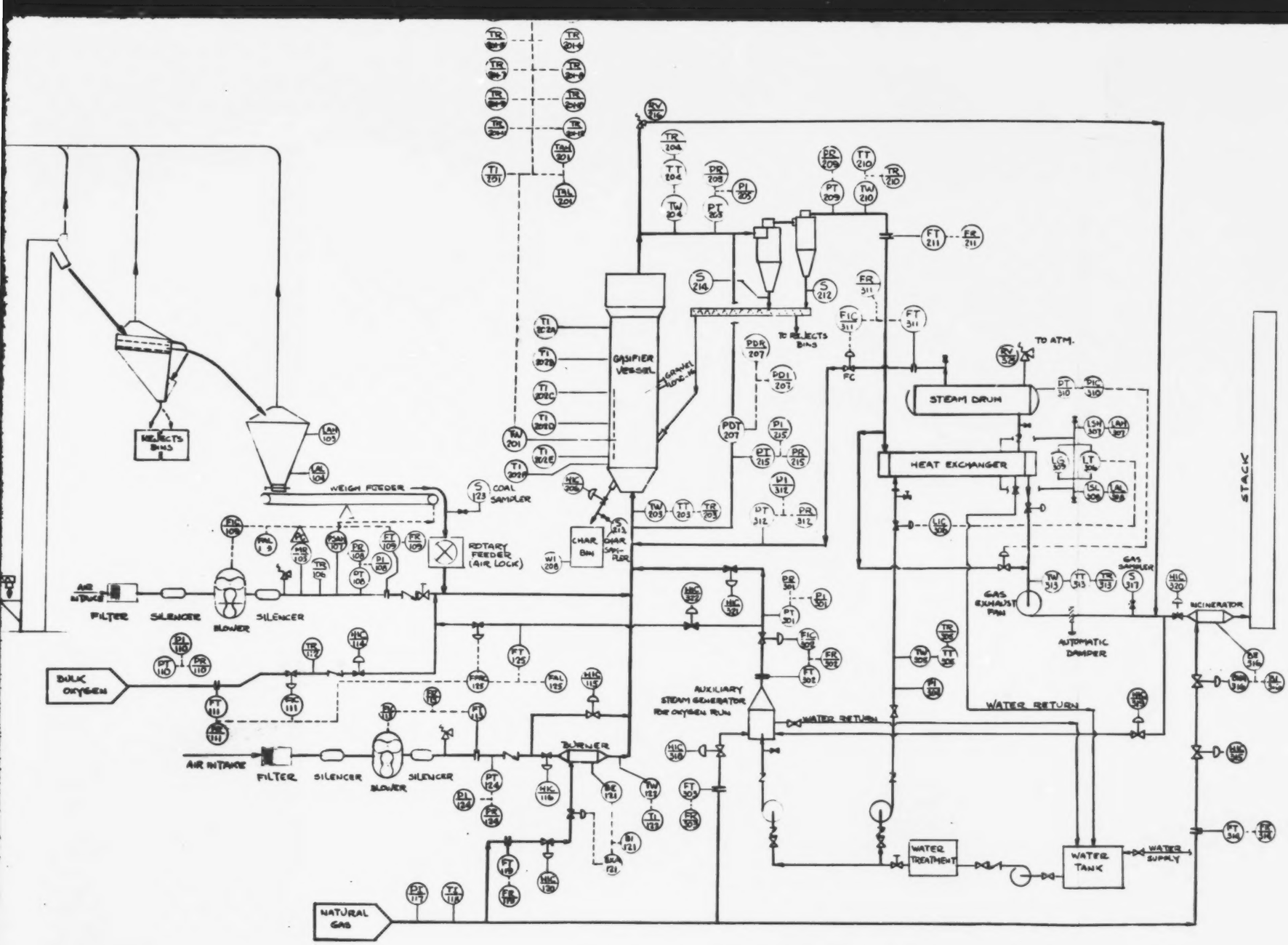
No	DATE	REVISIONS	BY	CHK	APP	No	DATE	REVISIONS	BY	CHK	APP
1											

HALF-SIZE PRINT
USE GRAPHIC SCALES

PROFESSIONAL STAMP

snc

DESIGNED J. PIENK
DRAWN R. TRUD
CHECKED P. ROCH
SCALE NONE
DATE JULY 12



PRELIMINARY

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			1					

No	DATE	REVISIONS	BY	CHK	APP

HALF-SIZE PRINT USE GRAPHIC SCALES

PROFESSIONAL STAMP

snc Surveyer, Nenniger & Chénevert Inc.
1, Complexe Desjardins, Montreal, Canada

DESIGNED J. PIENKOWSKI	APPROVED Project Engineer
DRAWN R. TRUDEL	Project Engineering Manager
CHECKED P. ROCHESTER	Client
SCALE NONE	
DATE July 12/82	

CLIENT: DEPARTMENT OF ENERGY, MINES AND RESOURCES — CANMET

PROJECT: PDU SPOUTED BED GASIFIER

TITLE: P&I DIAGRAM

CONTR No	DRAWING CODE	SERIAL No	REV
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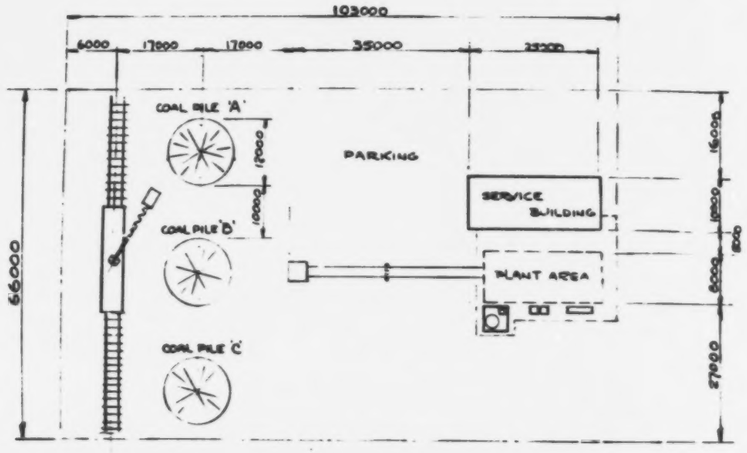
AO SIZE 4003-118/1

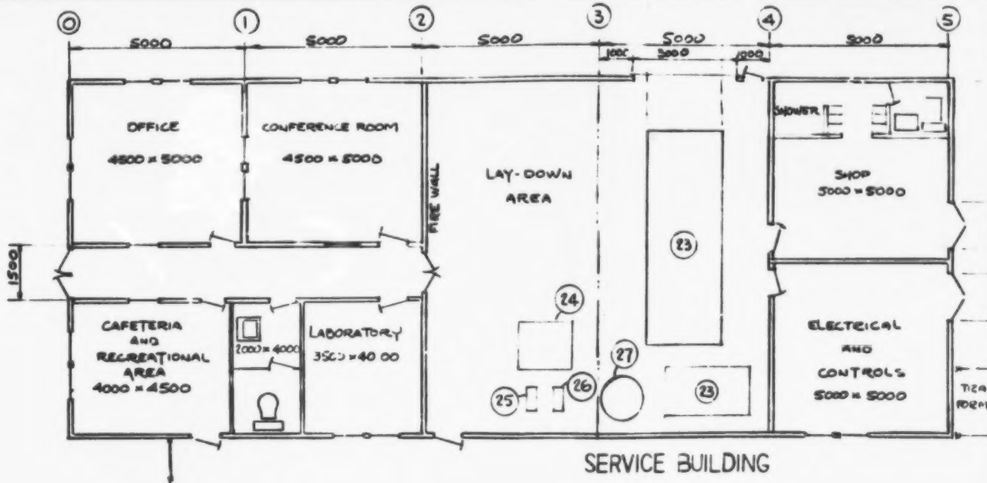
3 2 1



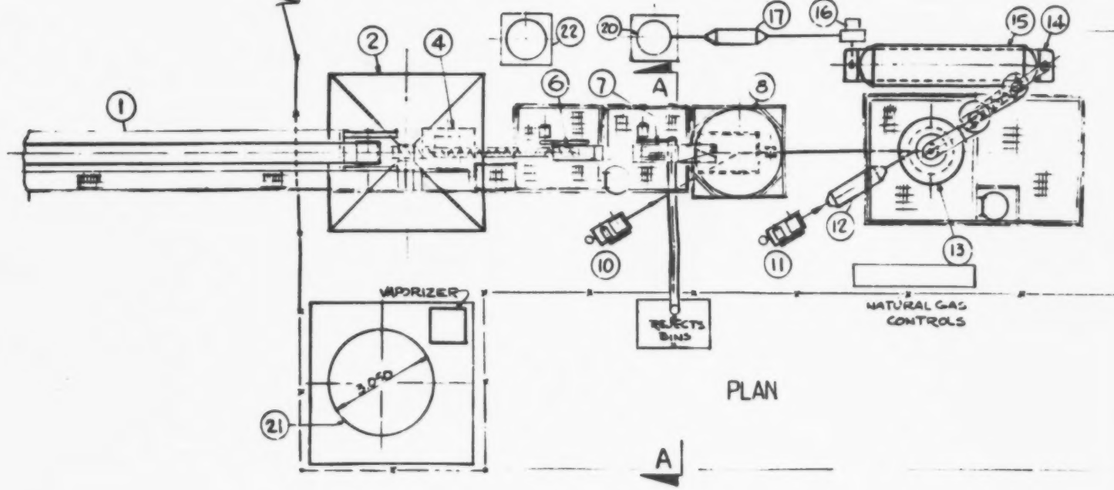
KEY PLAN

1:500

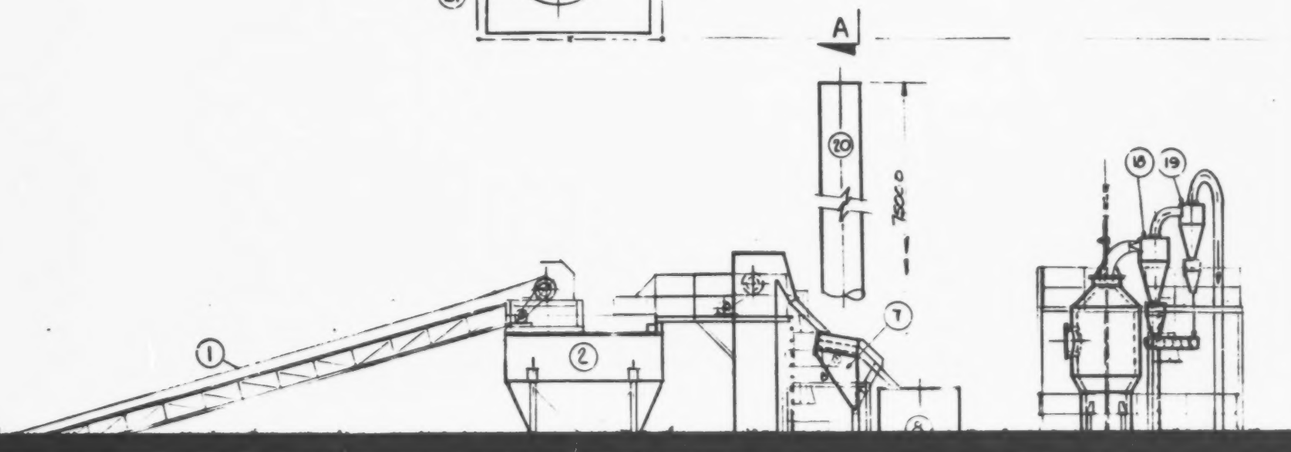
EQUIPMENT LIST			
ITEM Nº	DESCRIPTION	ITEM Nº	DESCRIPTION
1	COAL CONVEYOR WITH LOADING HOPPER.	21	CRYOGENIC BULK OXYGEN SUPPLY TANK AND VAPORIZER
2	RAW COAL BIN, GRIZZLY, COVER, 40 t CAP	22	BAGHOUSE DUST COLLECTOR C/W FAN, DUCTING AND DISCHARGE VALVE
3	SCREW CONVEYOR AND CHUTES	23	PACKAGED STEAM BOILER FOR OPERATION WITH OXYGEN, C/W DE AERATOR AND PUMPS
4	HAMMERMILL	24	WATER TREATMENT UNIT FOR STEAM GENERATOR AND AUXILIARY STEAM BOILER
5	SCREW CONVEYOR AND CHUTES	25	FEEDWATER PUMP FOR STEAM GENERATOR/ HEAT EXCHANGER.
6	BUCKET ELEVATOR AND CHUTES	26	BOILER FEEDWATER PUMP ASSEMBLY.
7	VIBRATING SCREEN 1200×600 mm	27	WATER TANK
8	CRUSHED COAL BIN 10 t CAP.		
9	WEIGH FEEDER ASSEMBLY, SAMPLER AND AIR LOCK FEEDER.		
10	COAL/AIR BLOWER SYSTEM, C/W S.S. PIPING AND VALVE TRAIN.		
11	PREHEAT AIR BLOWER, C/W PIPING, VALVE TRAIN TO BURNER		
12	BURNER ASSEMBLY		
13	PDU SPOUTED BED GASIFIER VESSEL ASS'Y		
14	STEAM GENERATOR / HEAT EXCHANGER		
15	STEAM DRUM		
16	PRODUCT GAS FAN		
17	PRODUCT GAS BURNER ASS'Y		
18	CYCLONE 1		
19	CYCLONE 2		
20	EXHAUST STACK		



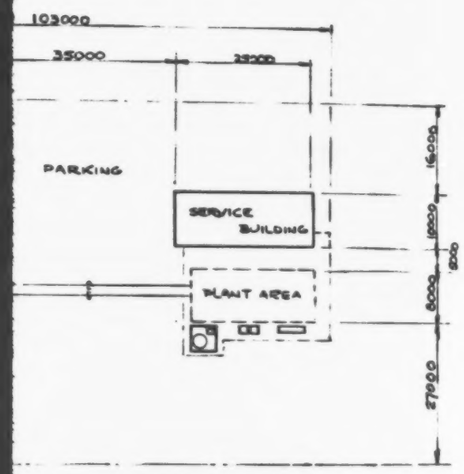
SERVICE BUILDING



PLAN

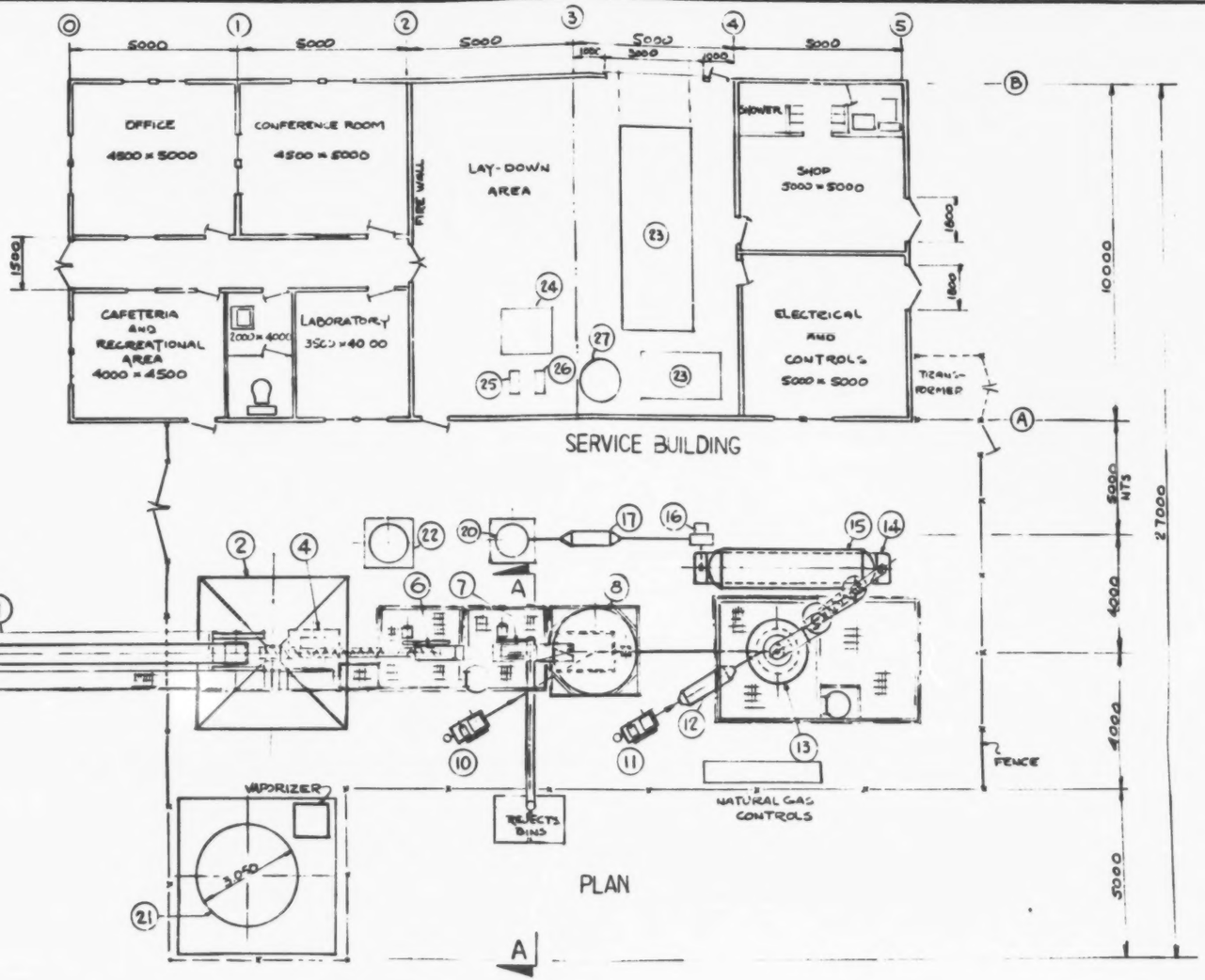


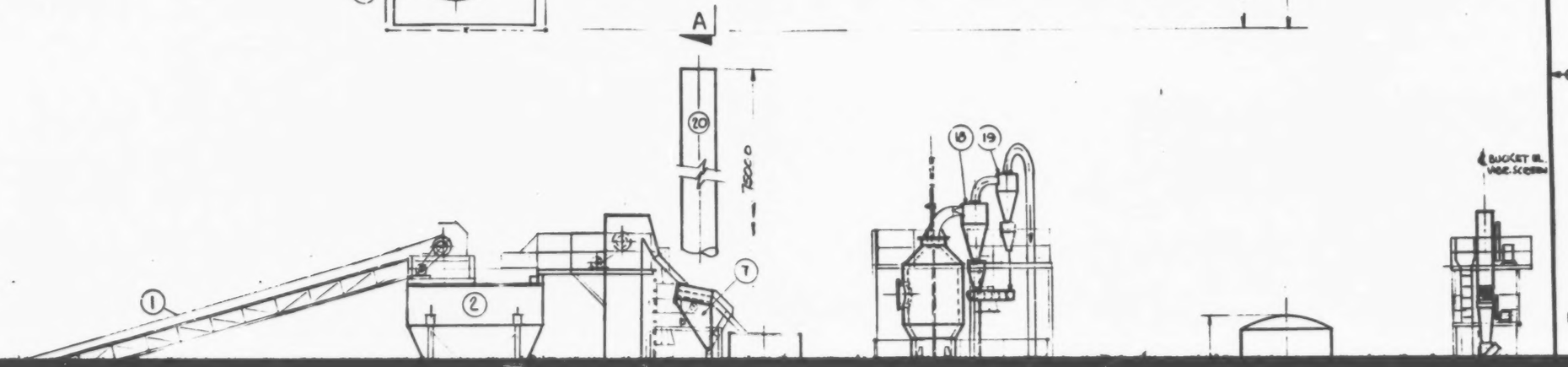
KEY PLAN



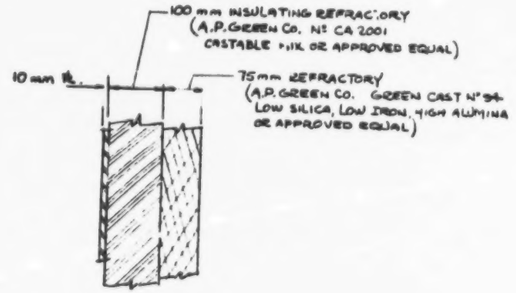
KEY PLAN
1:500

ITEM Nº	DESCRIPTION
1	CRYOGENIC BULK OXYGEN SUPPLY TANK AND VAPORIZER
2	BAGHOUSE DUST COLLECTOR C/W FAN, DUCTING AND DISCHARGE VALVE
3	PACKAGED STEAM BOILER FOR OPERATION WITH OXYGEN, C/W DE-AERATOR AND PUMPS
4	WATER TREATMENT UNIT FOR STEAM GENERATOR AND AUXILIARY STEAM BOILER
5	FEEDWATER PUMP FOR STEAM GENERATOR/ HEAT EXCHANGER.
6	BOILER FEEDWATER PUMP ASSEMBLY.
7	WATER TANK



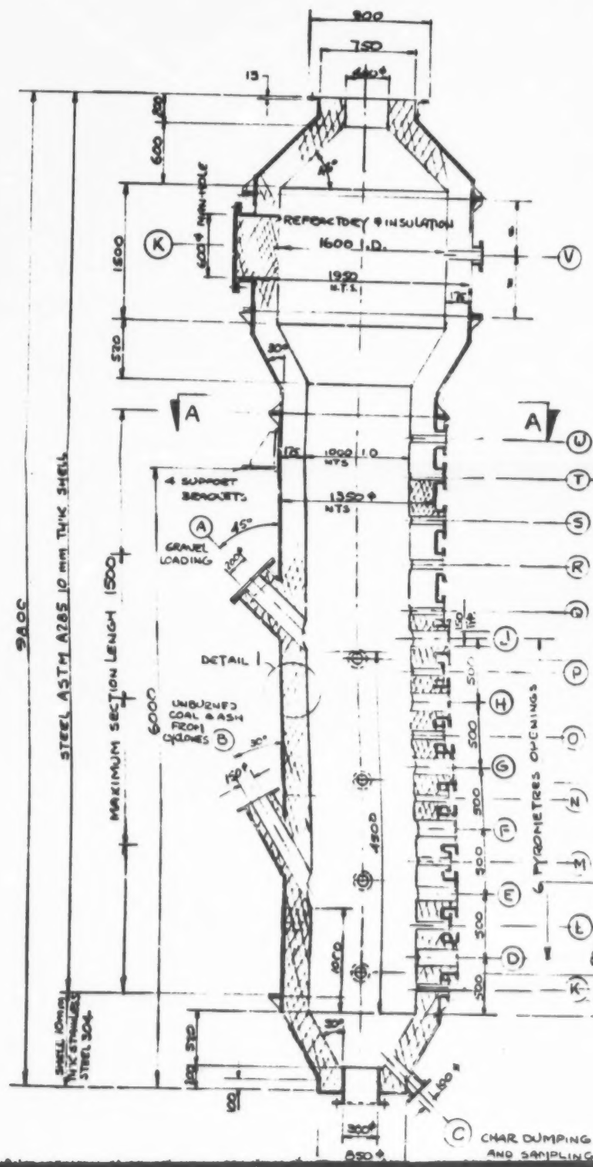


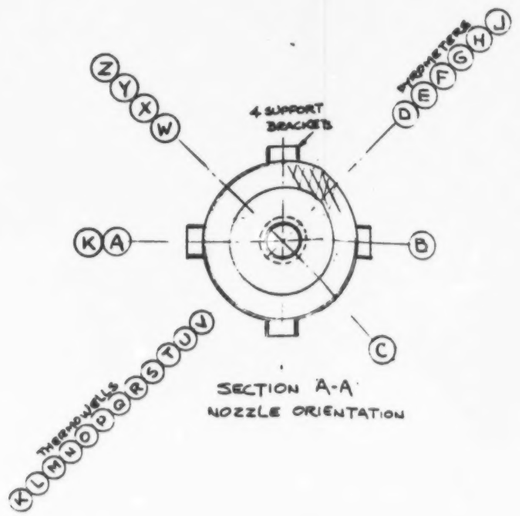
0 10 20 30 40 ℄ 60 70 80 90 100 mm


100 mm INSULATING REFRACTORY
(A.P. GREEN CO. Nº CA 2001
CASTABLE MIX OR APPROVED EQUAL)
10 mm
75mm REFRACTORY
(A.P. GREEN CO. GREEN CAST Nº 94
LOW SILICA, LOW IRON, HIGH ALUMINA
OR APPROVED EQUAL)

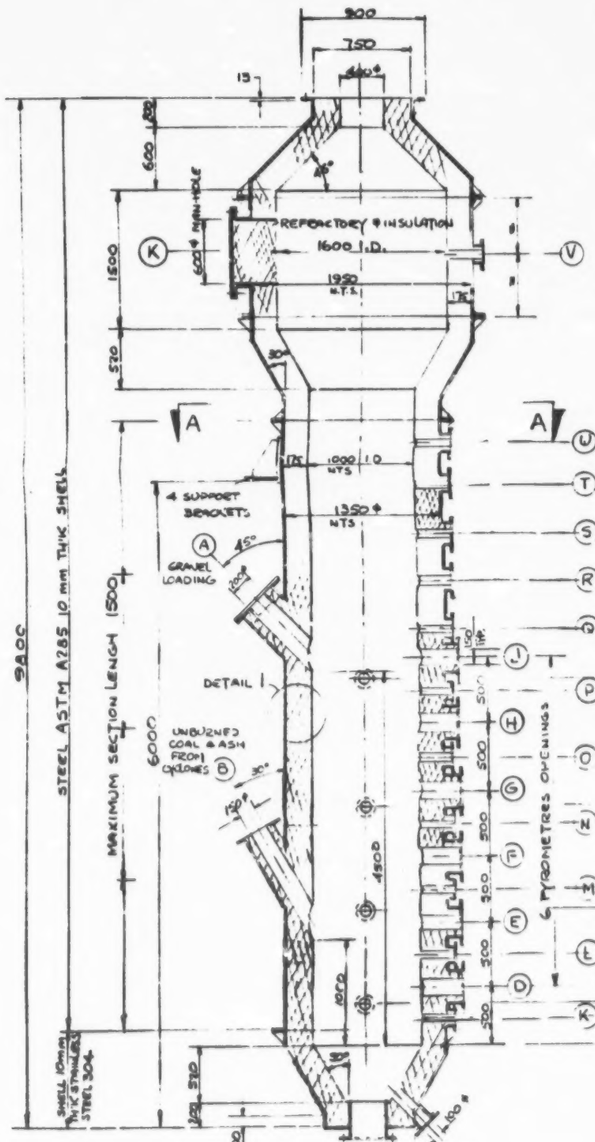
DETAIL 1

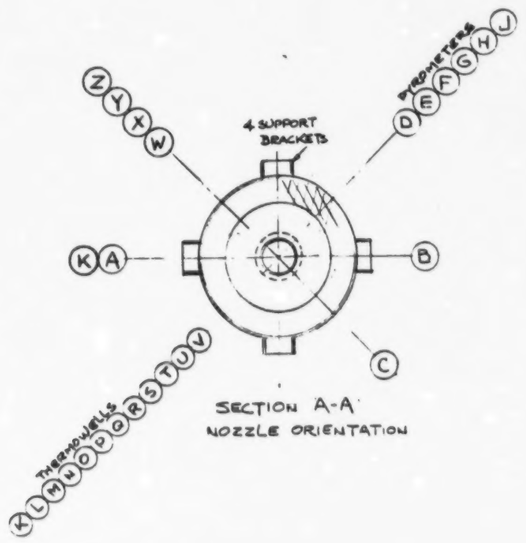
1:5





SECTION A-A
NOZZLE ORIENTATION





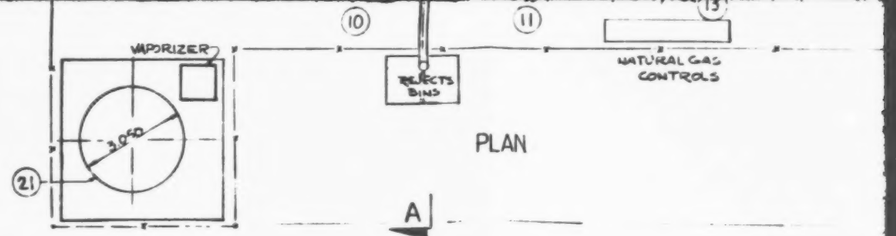
SECTION A-A
NOZZLE ORIENTATION

m INSULATING REFRACTORY
A.P. GREEN CO. Nº CA 2001
ASTABLE MIX OR APPROVED EQUAL)

75mm REFRACTORY
(A.P. GREEN CO. GREEN CAST Nº 94
LOW SILICA, LOW IRON, HIGH ALUMINA
OR APPROVED EQUAL)

KEY PLAN

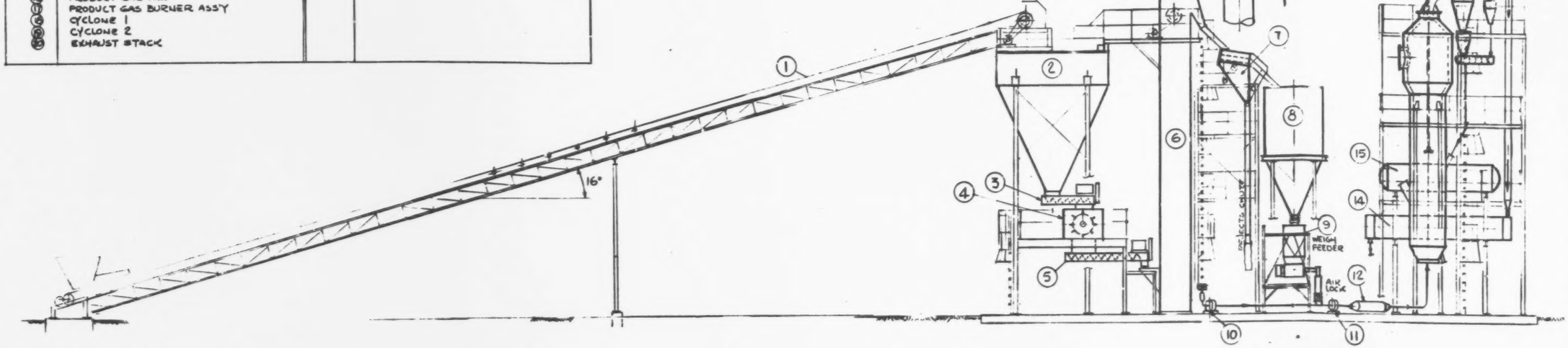
1:500



PLAN

EQUIPMENT LIST

ITEM Nº	DESCRIPTION	ITEM Nº	DESCRIPTION
1	COAL CONVEYOR WITH LOADING HOPPER.	21	CRYOGENIC BULK OXYGEN SUPPLY TANK AND VAPORIZER
2	RAW COAL BIN, GRIZZLY, COVER, 40 t CAP	22	BAGHOUSE DUST COLLECTOR C/W FAN, DUCTING AND DISCHARGE VALVE
3	SCREW CONVEYOR AND CHUTES	23	PACKAGED STEAM BOILER FOR OPERATION WITH OXYGEN, C/W DE AERATOR AND PUMPS
4	HAMMERMILL	24	WATER TREATMENT UNIT FOR STEAM GENERATOR AND AUXILIARY STEAM BOILER
5	SCREW CONVEYOR AND CHUTES	25	FEEDWATER PUMP FOR STEAM GENERATOR/ HEAT EXCHANGER.
6	BUCKET ELEVATOR AND CHUTES	26	BOILER FEEDWATER PUMP ASSEMBLY.
7	VIBRATING SCREEN 1200×600 mm	27	WATER TANK
8	CRUSHED COAL BIN 10 t CAP.		
9	WEIGH FEEDER ASSEMBLY, SAMPLER AND AIR LOCK FEEDER		
K	COAL/AIR BLOWER SYSTEM, C/W S.S PIPING AND VALVE TRAIN.		
11	PREHEAT AIR BLOWER, C/W PIPING, VALVE TRAIN TO BURNER		
12	BURNER ASSEMBLY		
13	PDU SPOUTED BED GASIFIER VESSEL ASS'Y		
14	STEAM GENERATOR / HEAT EXCHANGER		
15	STEAM DRUM		
16	PRODUCT GAS FAN		
17	PRODUCT GAS BURNER ASS'Y		
18	CYCLONE 1		
19	CYCLONE 2		
20	EXHAUST STACK		



ELEVATION

ISSUE	REV	DATE	STATUS & DISTRIBUTION	ISSUE	REV	DATE	STATUS & DISTRIBUTION

RECORD OF DRAWING ISSUE

No	REFERENCE DRAWINGS

No	REFERENCE DRAWINGS

No	DATE	REVISIONS	BY	CHK	APP
PB	JULY 16/82	SERVICE BUILDING ALTERED			

No	DATE	REVISIONS	BY	CHK	APP

HALF-SIZE PRINT
USE GRAPHIC SCALES

PROFESSIONAL STAMP

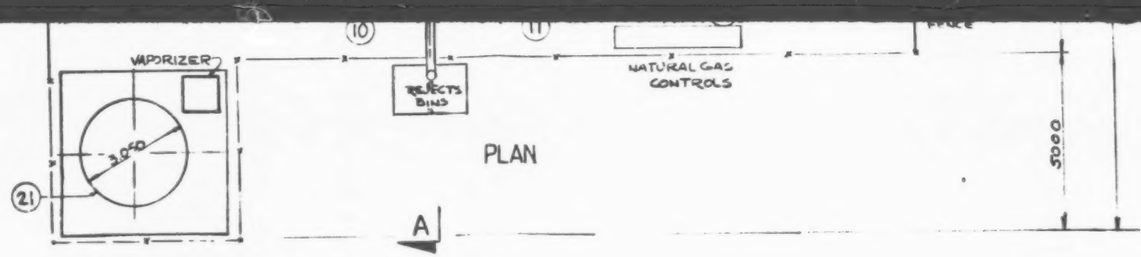
SNC Surveyo
I. Comple

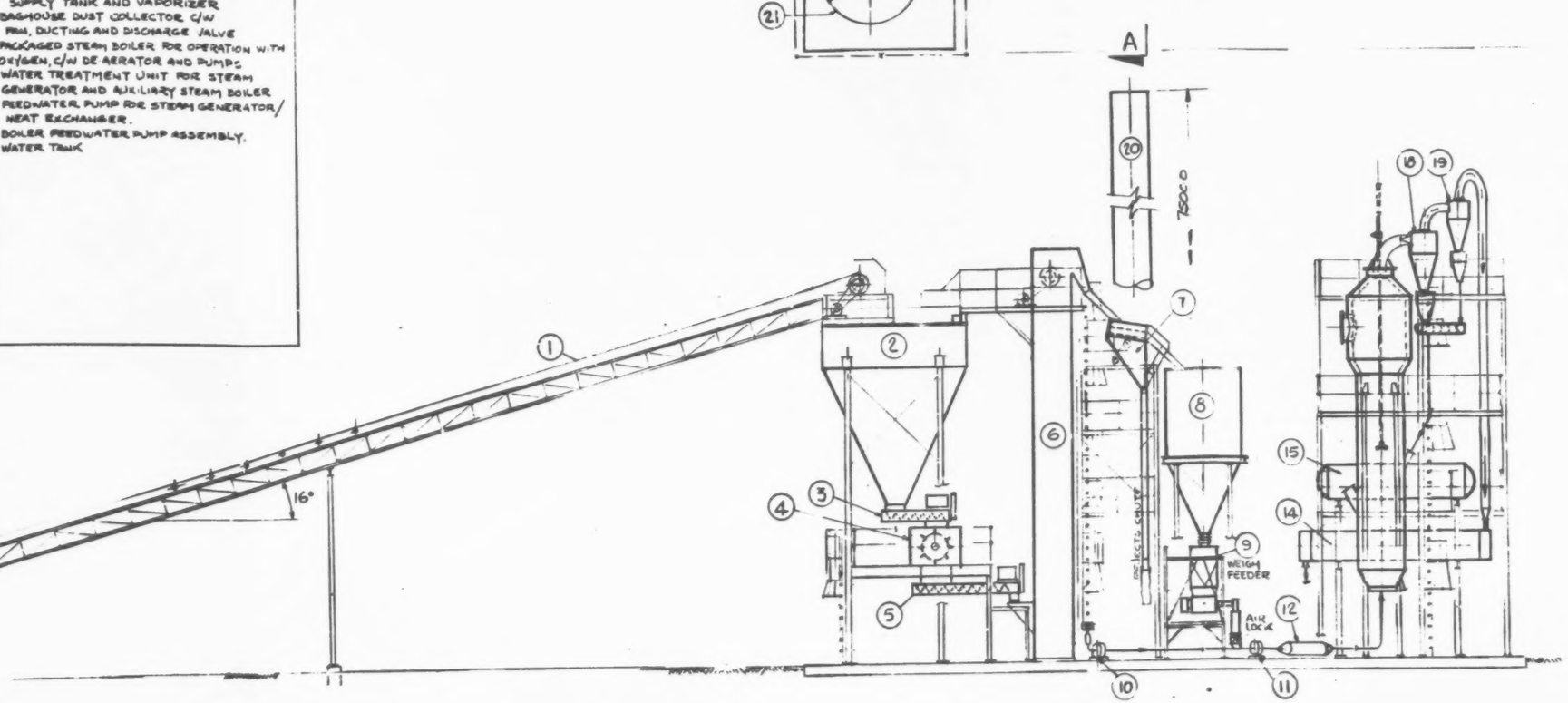
DESIGNED P. ROCHEST
DRAWN R. TAUDEL
CHECKED P. ROCHEST
SCALE 1:75 & 1:5
DATE JULY 16/82

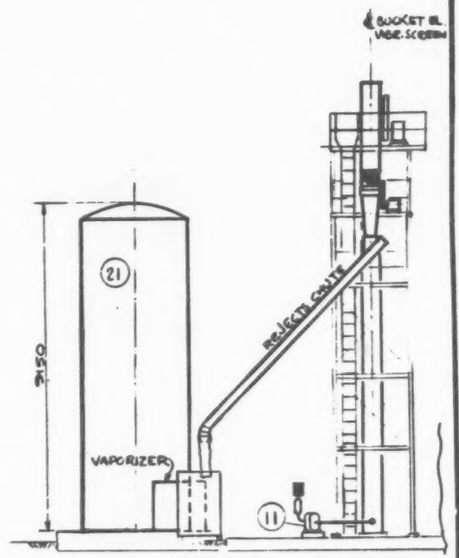
4 3 2

PLAN

ITEM Nº	DESCRIPTION
21	CRYOGENIC BULK OXYGEN SUPPLY TANK AND VAPORIZER
22	BAGHOUSE DUST COLLECTOR C/W FAN, DUCTING AND DISCHARGE VALVE
23	PACKAGED STEAM BOILER FOR OPERATION WITH OXYGEN, C/W DE AERATOR AND PUMPS
24	WATER TREATMENT UNIT FOR STEAM GENERATOR AND AUXILIARY STEAM BOILER
25	FEEDWATER PUMP FOR STEAM GENERATOR/ HEAT EXCHANGER.
26	BOILER FEEDWATER PUMP ASSEMBLY.
27	WATER TANK







NOTES
1-DUST COLLECTION EQUIPMENT OMITTED FOR CLARITY

PRELIMINARY

No	DATE	REVISIONS	BY	CHK	APP
A	16/8/82	SERVICE BUILDING ALTERED			

HALF-SIZE PRINT
USE GRAPHIC SCALES

PROFESSIONAL STAMP

SNC Surveyer, Nenniger & Chênevert Inc.
1, Complexe Desjardins, Montréal, Canada

DESIGNED P. ROCHESTER
DRAWN R. TRUDEL
CHECKED P. ROCHESTER
SCALE 1:75 & 1:500
DATE JULY 16/82
APPROVED
Project Engineer
Project Engineering Manager
Client

CLIENT DEPARTMENT OF ENERGY, MINES AND RESOURCES — CANMET
PROJECT PDU SPOUTED BED GASIFIER
TITLE GENERAL ARRANGEMENT

CONTR No	DRAWING CODE	SERIAL No	REV
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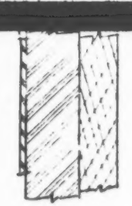
AD SIZE 4000-16 E/1



DETAIL 1
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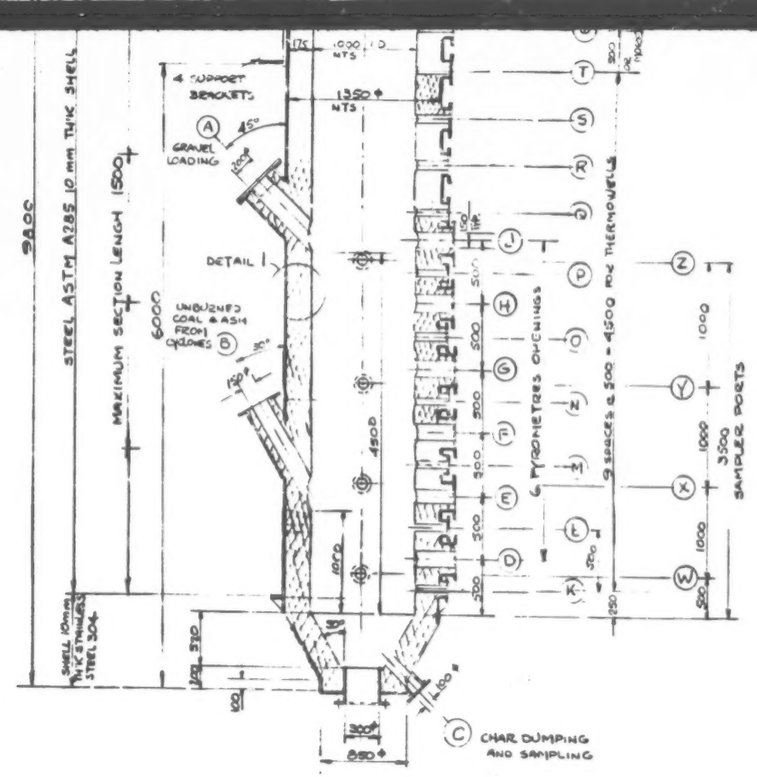


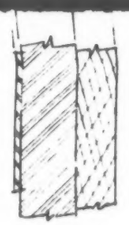
RECORD OF DRAWING ISSUE								No	REFERENCE DRAWINGS	No	REFERENCE DRAWINGS	No	DATE	REVISIONS	BY	CHK	APP	No	DATE	REVISIONS	BY	CHK	APP	PROFESSIONAL STAMP
ISSUE	REV	DATE	STATUS & DISTRIBUTION	ISSUE	REV	DATE	STATUS & DISTRIBUTION					1												

HALF-SIZE PRINT
USE GRAPHIC SCALES

DESIGNED P.
DRAWN R.
CHECKED P.
SCALE 1:2
DATE Ju

4 3 2

LOW SILICA, LOW IRON, HIGH ALUMINA
OR APPROVED EQUAL)



DETAIL 1
1:5

NOTES
1-MAXIMUM TEMPERATURE 1090°C.
OPERATING PRESSURE 100 Pag
DESIGN PRESSURE 400 kPag
2-ALL NOZZLE FLANGES 1050 kPag STD
3-ALL GASKETS TO BE ASBESTOS 6mm THK
4-SI UNITS USED THROUGHOUT

PRELIMINARY

REFERENCE DRAWINGS	No	REFERENCE DRAWINGS

No	DATE	REVISIONS	BY	CHK	APP
1					

No	DATE	REVISIONS	BY	CHK	APP

HALF-SIZE PRINT
USE GRAPHIC SCALES

PROFESSIONAL STAMP

snc Surveyer, Nenniger & Chénevert Inc.
1, Complexe Desjardins, Montreal, Canada

DESIGNED P. ROCHESTER	APPROVED Project Engineer
DRAWN R. TRUDEL	
CHECKED P. ROCHESTER	Project Engineering Manager
SCALE 1:25	Client
DATE JULY 12/82	

CLIENT
DEPARTMENT OF ENERGY, MINES AND RESOURCES — CANMET

PROJECT
PDU SPOUTED BED GASIFIER

TITLE
GASIFIER VESSEL

CONTR No	DRAWING CODE	SERIAL No	REV
6521	0.0.0.3 4 5 0 0 0.0	0.0.0.3	P c

AO SIZE 4000 × 1 E/1

3 2 1

C B A

LOVELL - FORM A-810(B)
PROCÉDÉ Plasdex R. PROCESS
MONTRÉAL, QUÉBEC

APPENDIX I

SIMULATOR PROGRAM

APPENDIX I

SIMULATOR PROGRAM

A listing of the computer program simulating a spouted bed gasifier is being separately forwarded to the CANMET Scientific Authority. This program uses the simulator input data given in Appendix D.

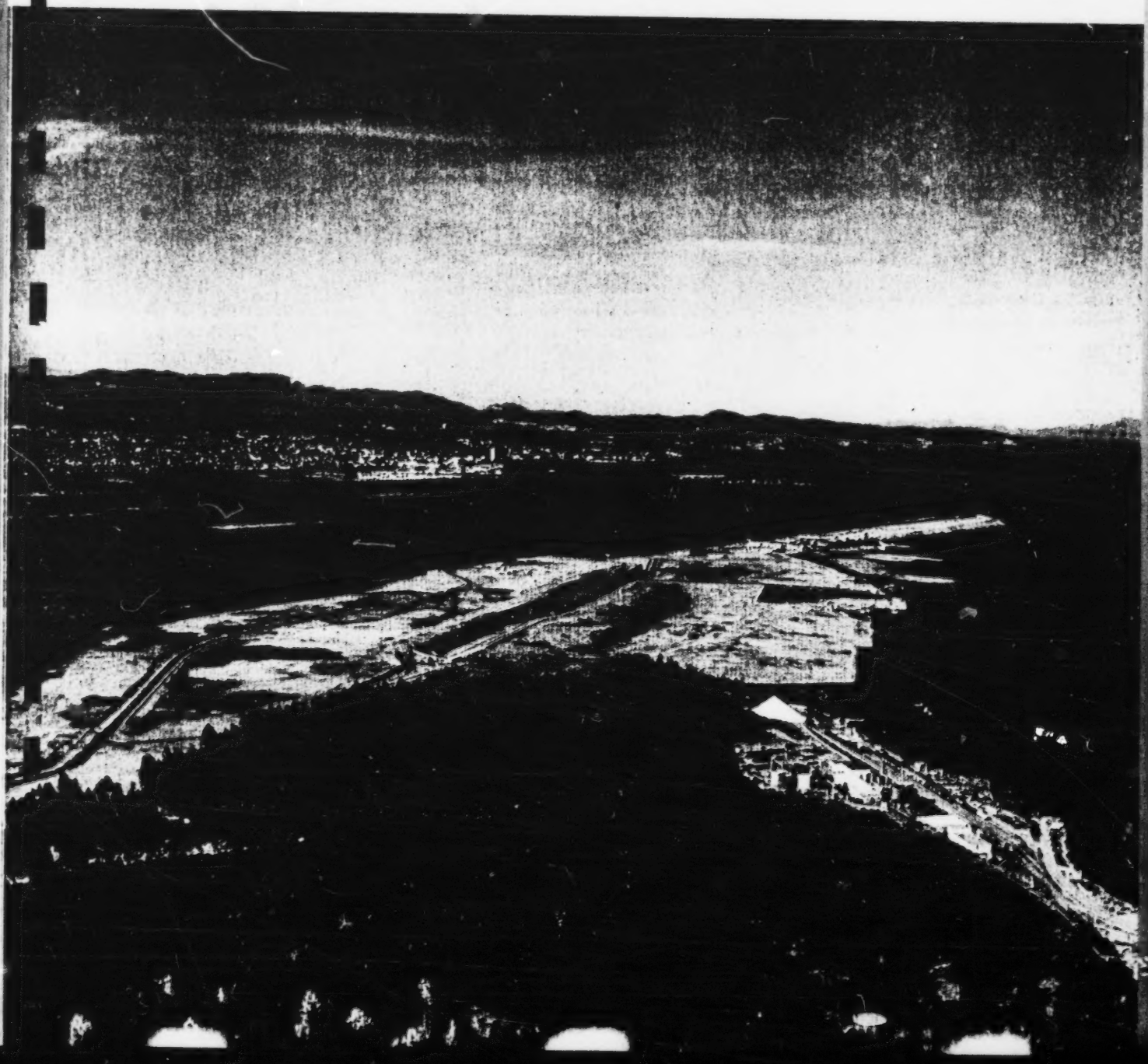
LOVELL - FORM A-610(B)
PROCÉDÉ Plandex® PROCESS
MONTRÉAL, QUÉBEC

APPENDIX J

LITERATURE ON DUKE POINT INDUSTRIAL PARK

DUKE POINT INDUSTRIAL PARK

345 AFFORDABLE ACRES INCLUDING A DEEP-SEA SHIPPING TERMINAL



DUKE POINT INDUSTRIAL PARK

HUB OF VANCOUVER ISLAND INDUSTRY

Transportation

Duke Point offers quick access to all points:

Land

- City of Nanaimo — *20 min.*
- Island Highway running north of Nanaimo and Trans-Canada running south of Nanaimo — *7 min.*
- C.P. Rail freight service — *18 min.*
- Island E & N passenger rail service to Victoria and Comox — *18 min.*

Sea

- B.C. Ferry service to Vancouver — *25 min.*
- C.P. Rail ferry freight service to Vancouver — *20 min.*
- Nanaimo Harbour Commission three-berth inner harbour facility — *20 min.*

Air

- Cassidy Airport — *20 min.*
- Air B.C. 25 minute seaplane service to downtown Vancouver — *20 min.*

DUKE POINT INDUSTRIAL PARK

GENERAL INFORMATION

Diversification of Usage

Area A – 117 acres for general industry with lots from 5 to 10 acres
Area B – 110 acres for heavy industry with lots from 30 to 40 acres
Area C – 63 acre shipping terminal
Area D – 24 acre proposed petroleum tank farm
Area E – 30 acre completed sawmill
Total – 345 Acres of Prime Industrial Land

Industrial

Duke Point is in the heart of the Island industrial development area with access to:

- forest products manufacturing
- fishing: salmon, herring, bottom fish, aquaculture, mariculture and the Pacific Biological Station
- caustic and chlorine manufacturing
- export shipping (lumber, newsprint, plywood and pulp)
- import shipping (salt)
- primary and secondary industry processing and manufacturing
- undeveloped proven coal resources
- undeveloped natural gas resources
- proposed development of a research park in the City of Nanaimo

Forest Product Companies

Within a 50-mile radius of two dozen sawmills and pulpmills including:

- MacMillan Bloedel at Harmac, Chemainus and Port Alberni
- Mayo Forest Products in Nanaimo

- C. Itoh Pacific Logging (CIPA) in Nanaimo
- Crown Zellerbach at Campbell River
- Domans at Cowichan, Ladysmith and Duke Point

Services

Storm and sanitary sewers, water, hydro and paved roads.

Energy

- Hydro electrical expansion on Vancouver Island
- proposed natural gas pipeline to Vancouver Island

Zoning

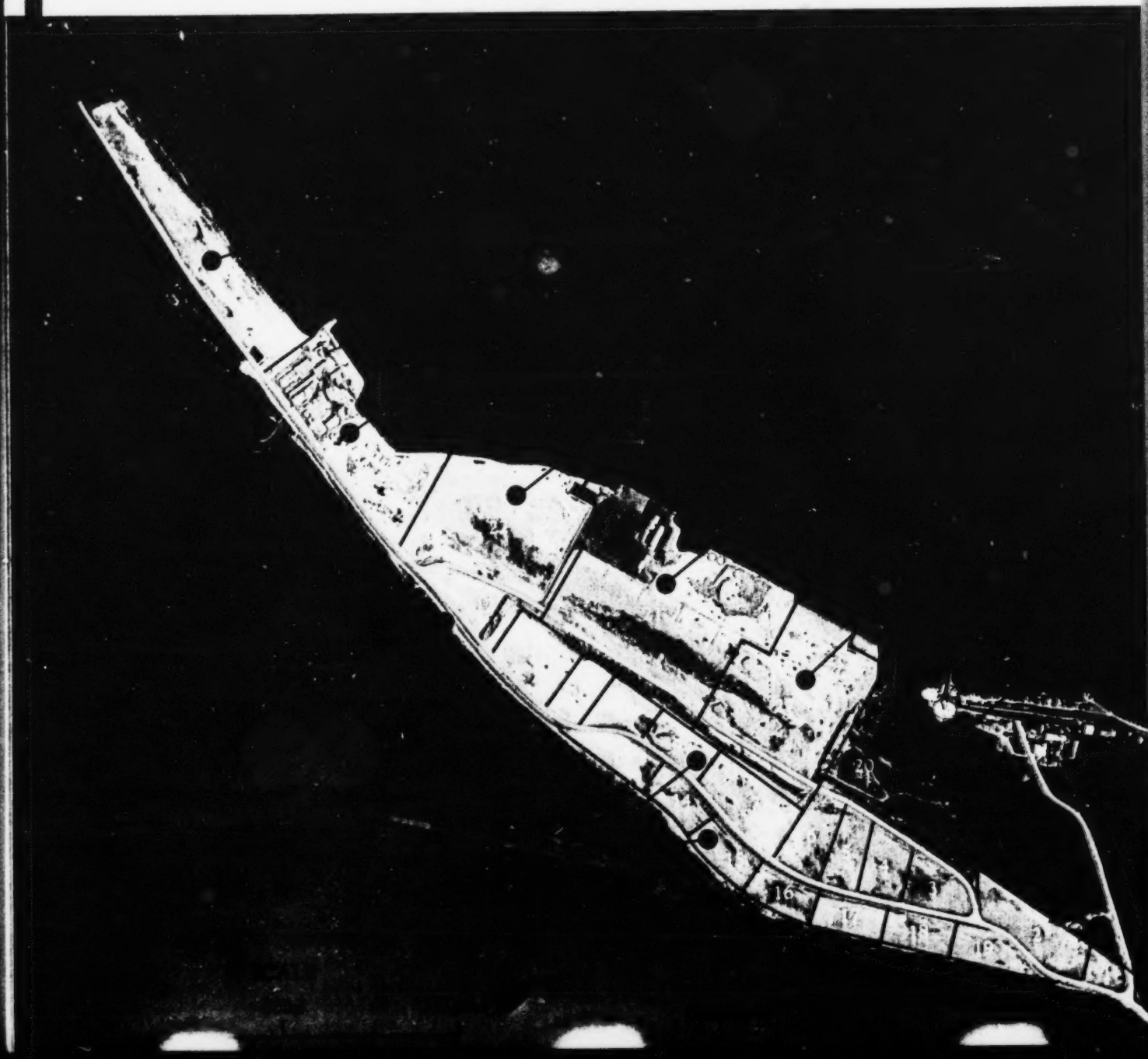
For heavy industrial use.

For more information, call or write
Duke Point Development Ltd.
272 Granville Square,
Vancouver, British Columbia V6C 1S4
Telephone: 112-800-663-9210

Duke Point Development Ltd. is a wholly-owned subsidiary of the B.C. Development Corporation.

DUKE POINT INDUSTRIAL PARK

EXCELLENT SELECTION OF PRIME SITES



DUKE POINT INDUSTRIAL PARK

EXCELLENT SELECTION OF PRIME SITES

LOT #	ACREAGE	PRICE/ACRE	TOTAL PRICE
1	5.1	$133,000	$ 678,300
2	10.3	133,000	1,369,900
3	5.5	133,000	731,500
4	5.5	133,000	731,500
5	5.5	133,000	731,500
6	6.8	133,000	904,400
7	10.6	133,000	1,409,800
8	5.1	133,000	678,300
9	5.1	133,000	678,300
10	5.1	133,000	678,300
11	9.8	133,000	1,303,400
12	7.2	133,000	957,600
13	5.1	133,000	678,300
14	5.1	133,000	678,300
15	5.1	133,000	678,300
16	5.1	133,000	678,300
17	5.1	133,000	678,300
18	5.1	133,000	678,300
19	5.1	133,000	678,300
20	24.1	N/A	N/A
21	62.8	N/A	N/A
22	37.5	176,900	6,633,750
23	30.4	N/A	N/A
24	22.1	176,900	3,909,490
27	40.5	176,900	7,164,450

N/A — Not Available

May 28, 1982

DUKE POINT INDUSTRIAL PARK

PRIME INDUSTRIAL LAND AT AFFORDABLE PRICES

Variety of Prime Sites

Duke Point Industrial Park* is the prime heavy industrial land development on Vancouver Island. It adjoins the new Duke Point **Shipping Terminal**, which will accommodate the largest deep-sea forest products carriers.

The 63-acre shipping terminal consists of two berths capable of accommodating 700 foot vessels of up to 45 feet draft all year around. The facility will specialize in the transshipment of forest products.

In addition, the completed Doman **Sawmill** occupies 30-acres and a proposed 24-acre **Petroleum Tank Farm** is tentatively planned to meet demands for liquid petroleum products storage.

Two proposed 40-acre and one 30-acre **Major Industrial Sites** as well as the 117-acre area for **General Industry, Manufacturing** and **Warehousing** combine to make Duke Point one of the outstanding manufacturing and export facilities on the West Coast.

Duke Point is particularly attractive because the development is fully serviced, has basic environmental approval, plentiful water supply, an attractive community with a stable work force, and additional major quantities of hydro power in 1984.

*This project is partially funded through the Federal-Provincial I.D.S.A. Program.

Affordable

Prime land is available for sale or lease, with sale prices starting at **$133,000/Acre.**

25% down. . . with an Agreement for Sale is all that's needed as a down payment. Our staff are available to help you put together an affordable financial package that includes a number of attractive incentives including **special low interest rates** on the balance of the loan, which are available to qualified applicants over a two year term.

Lifestyle

The City of Nanaimo offers all amenities one would expect servicing a regional district population of 80,000. In addition, the island-dotted coastal waters are a boater and fisherman's paradise with the hunter, skier and golfer also enjoying their outdoor activities in this mild climate. A further benefit, available at Duke Point, is the greenbelt bordering the Nanaimo River Estuary, which challenges Duke Point employees to enjoy recreational fishing and outdoor activities before or after work!

Province of British Columbia

Government of Canada / Gouvernement du Canada

News Release

from the Government of Canada and the Province of British Columbia

No. 34495
FOR RELEASE AT 2:30 P.D.T.
ON MAY 28, 1982

FEDERAL AND PROVINCIAL MINISTERS ATTEND DUKE POINT OPENING

VICTORIA - Duke Point Industrial Park at Nanaimo, the largest and most important industrial land complex on Vancouver Island, was officially opened today by Herb Gray, federal Minister of Regional Economic Expansion (DREE) and Industry, Trade and Commerce; and by Don Phillips, provincial Minister of Industry and Small Business Development.

Creation of the $28 million, 114 hectare industrial park began in 1977. Its construction, which involved a major 28 hectare reclamation project, was made possible by the cooperation and joint funding of the federal and provincial governments. Thirteen million dollars was contributed under the Canada/B.C. Industrial Development Subsidiary Agreement (IDSA).

Developed by Duke Point Development Ltd., a subsidiary of the B.C. Development Corporation, the industrial park is adjacent to a major deep sea port which opened in September, 1981 and is operated by the Nanaimo Harbour Commission.

Strategically located to provide convenient export facilities for Vancouver Island's forest industry and other commodities, the new 25 hectare port includes two deep sea wharves, two floating barge terminals, a paved assembly area and warehouse space.

Forest products from Doman Industries' sawmill, the first plant in operation at Duke Point, are already being handled at the shipping terminal.

Serviced industrial land at Duke Point has been zoned for heavy industry. Fifty-six hectares of waterfront property have been allocated for large operations needing lots 12 to 16 hectares in size and 47.3 hectares

more...

have been subdivided into lots under four hectares for general industry use. Petro Canada has an option on 9.6 hectares for a proposed petroleum tank farm.

Close proximity of the major sites to the shipping terminal means substantial savings in handling and transportation charges.

All land is being marketed by the B.C. Development Corporation, with prices starting at $328,510 per hectare ($133,00 an acre).

Duke Point is uniquely serviced to attract new industry, particularly forest products. A water line specifically enlarged to 760 mm, capable of delivering up to 68 million litres per day, provides the capacity to serve two thermo mechanical pulpmills. Log storage has been made available in the Nanaimo estuary as the result of careful studies and agreement from the federal Department of Fisheries and Oceans. Increased hydro power capacity will be available in late 1983 from the new Cheekeye-Dunsmuir Crossing to Vancouver Island.

Located 20 minutes from downtown Nanaimo, Duke Point has been designed under strict environmental protection policies. A greenbelt area shields the industrial area from downtown Nanaimo and is part of the extensive measures that were taken to protect the Nanaimo estuary salmon fishing.

The greenbelt and roads at Duke Point were dedicated to the City of Nanaimo at the opening ceremony with Mayor Frank Ney accepting on behalf of the City.

Funding of projects under the IDSA is cost-shared equally by DREE and the B.C. Ministry of Industry and Small Business Development.

For further information contact:

John Thomson
Ministry of Industry and Small Business Development
6th Floor, 1405 Douglas Street
Victoria, British Columbia
V8W 3C1
Telephone: 387-5095

Ralph Van Nes
Department of Regional Economic Expansion
600 - 1175 Douglas Street
Victoria, British Columbia
V8W 2E1
388-0198